RTCA Free Flight Select Committee

Safe Flight 21 Steering Committee

Safe Flight 21 Technical/Certification Subgroup

ADS-B Link Evaluation Team (LET)

Phase One Link Evaluation Report

Status and Initial Findings

November 1999

Contents

1. Introduction

This report summarizes initial findings and current status of the ADS-B link evaluation commissioned by the Safe Flight 21 (SF21) Steering Committee consistent with the recommendations of the RTCA Free Flight Select Committee.

1.1 The Charge to the LET

The SF21 Steering Committee requested a technical evaluation of three ADS-B and situational awareness link candidates, namely 1090 MHz Extended Squitter, Universal Access Transceiver (UAT), and VHF Digital Link (VDL) Mode 4. The candidate links were to be evaluated to a common set of link evaluation criteria derived from the need to support the Free Flight Operational Enhancements specified in August 1998 by the RTCA Free Flight Select Committee. A Phase One Link Evaluation Report was to be produced before the end of 1999. The Terms of Reference for the LET are Appendix A to this report.

The LET began its activities in December 1998. The SF21 Steering Committee selected the co-chairs of the Team and approved the team's membership as recommended by the co-chairs (see Appendix B to this report). Team members included subject matter experts for each of the three ADS-B link candidates. Coordination with the Eurocontrol ADS program has been extensive, with Eurocontrol representatives involved in numerous important technical actions.

1.2 What This Report Is (and Is Not)

This report presents specific descriptions of the candidate systems, common link evaluation criteria and traffic scenarios, link evaluation methodology, initial findings, and actions which are recommended to complete the technical evaluation. The recommended actions reflect the Team's best engineering judgment of the follow-on work required to provide technical support toward an ADS-B link decision, coordinated internationally as appropriate. It should be emphasized that this decision will be based on a number of considerations in addition to the technical analyses discussed herein (e.g., cost/benefit, safety, and institutional/transitional issues as well as identified applications additional to those specified in the Free Flight Select Committee Operational Enhancements Document).

This report does NOT contain an ADS-B link recommendation.

Section 2 of this report provides an overview of the three candidate ADS-B/situational awareness links. Section 3 identifies the Link Evaluation Criteria developed by the LET and approved by the SF21 Steering Committee. Section 4 presents the technical evaluation approach agreed by the LET. Section 5 summarizes the status of the technical evaluation, provides initial findings, and recommends follow-on technical evaluation actions. Appendices to the report provide a significant level of supporting detail.

2. Overview of ADS-B/Situational Awareness Link Candidates

The LET was asked to evaluate three candidate links. Two of these links, 1090 MHz Extended Squitter and UAT, are wide-band links operating in the L-Band. The third, VDL Mode 4, is implemented using multiple narrow-band channels in the VHF Band. System descriptions of the three candidates, for link evaluation purposes, were prepared, to a common template, by respective subject matter experts (Appendices C, D, and E). While these system descriptions were reviewed by the LET and many LET comments incorporated, the descriptions were finalized by the subject matter experts. A summary table of technical characteristics of the three link candidates is included as Appendix F.

2.1 1090 MHz Extended Squitter

Mode S technology is widely used for aeronautical Secondary Surveillance Radar. The 1090 MHz Extended Squitter was developed as an extension to this technology for additional applications. Each Extended Squitter message consists of 112 bits. The data rate used is 1 megabit per second, within a message. Access to the 1090 MHz channel is randomized, and the channel is shared with current Air Traffic Control Remote Beacon System (ATCRBS) and Mode S responses to interrogations from ground-based radars and TCAS. The squitters proposed for ADS-B are "extended" in the sense that prior, TCAS acquisition, Mode S squitters contained 56-bit messages.

1090 MHz Extended Squitter formats for ADS-B and transmission rates have been defined in detail by the ICAO Secondary Surveillance Radar Improvement and Collision Avoidance System Panel (SICASP), in conjunction with RTCA Special Committee 186 and EUROCAE Working Group 51. Additional formats have been proposed by 1090 MHz Extended Squitter subject matter experts to support FIS-B and TIS-B (see section 3). An ADS-B MOPS for the 1090 MHz Extended Squitter is under development jointly by RTCA and EUROCAE. Avionics to support 1090 MHz Extended Squitter are under development by multiple manufacturers.

Appendix C is a description of the 1090 MHz Extended Squitter system proposed for evaluation by the LET.

2.2 Universal Access Transceiver (UAT)

The UAT was initially developed as part of an Independent Research and Development (IR&D) project at the Mitre Corporation. UAT is a "clean sheet" design, specifically developed for broadcast applications, both air- and ground-based, to support surveillance and situational awareness. Each UAT message consists of either 248 or 376 bits. The UAT data rate is approximately 1 megabit/second within a message. Access to the UAT medium is segregated within a 1 second frame between ground-based broadcast services (the first 188 milliseconds of the frame) and an ADS-B segment. While the design presumes coordination between ground-based broadcasts to reduce/eliminate message overlap, medium access within the ADS-B segment is randomized.

Standards for UAT are not currently under development. UAT trials to date have been on an experimental frequency of 966 MHz. UAT avionics have been developed for the SF21 program and will be supplied to the FAA Capstone Program in Alaska in 2000.

Appendix D is a description of the UAT system proposed for evaluation by the LET.

2.3 VHF Digital Link (VDL) Mode 4

VDL Mode 4 technology has been under development since the mid 1980's, initially in Sweden but more recently in a number of States. VDL Mode 4 uses two 25 KHz Global Signaling Channels (GSCs), with additional local channels used in areas with higher aircraft density. Access to the VDL Mode 4 medium, within a channel, is time-multiplexed, with a data rate of 19.2 kilobits/second within a message. The VDL Mode 4 system is "self-organizing" in the sense that each VDL Mode 4 unit autonomously determines which slot to use based on that unit's assessment of which slots within a channel are available. A single slot VDL Mode 4 message consists of 256 bits.

VDL Mode 4 technology has been proposed and demonstrated for a wide variety of aviation applications, including two-way, addressed aeronautical communications and local area augmentation to GNSS. The

LET, as directed by the SF21 Steering Committee, evaluated each candidate link solely with regard to its ability to support ADS-B, TIS-B, and FIS-B (see Section 3).

VDL Mode 4 standards are being developed by the ICAO Aeronautical Mobile Communications Panel (AMCP). Draft Standards and Recommended Practices (SARPS) as well as more detailed technical material are in the process of being validated by a VDL Mode 4 Validation Subgroup (VSG) commissioned by the AMCP. Subgroup 2 of EUROCAE WG 51 is chartered to develop a VDL Mode 4 MOPS; this work will be completed as soon as possible once the SARPS are approved. Some of the VDL Mode 4 system parameters have not yet been finalized by the VSG. Values for these parameters have been provided by the VDL Mode 4 subject matter experts for the purposes of link evaluation. VDL Mode 4 avionics are under development by multiple manufacturers. VDL Mode 4 trials have been conducted on experimental frequencies within both the Aeronautical Radionavigation and Aeronautical Telecommunications bands.

Appendix E is a description of the VDL Mode 4 system proposed for evaluation by the LET.

3. ADS-B/Situational Awareness Link Evaluation Criteria

The LET developed, and the SF 21 Steering Committee approved, technical link performance criteria based primarily upon two RTCA industry-consensus documents: the Joint Government/Industry Plan for Free Flight Operational Enhancements (the "Free Flight Operational Enhancements Document"), dated August 1998, and the ADS-B MASPS, RTCA DO-242 (the "ADS-B MASPS"). These documents do not require that the ADS-B/Situational Awareness link support either Differential GNSS (DGNSS) or two-way addressed aeronautical communications. Additional European consensus link evaluation criteria have been solicited from Eurocontrol, which presently is in the process of finalizing its ADS-B/situational awareness requirements.

In the absence of established standards, additional performance criteria were developed within the LET for the Traffic Information Service--Broadcast (TIS-B) and Flight Information Service--Broadcast (FIS-B). The development of TIS-B and FIS-B link evaluation criteria should NOT be viewed as a statement that these services must be provided on the same radio frequency link as is ADS-B; rather, the LET has been asked to evaluate the ability of each candidate ADS-B link to support these identified situational awareness services.

A further set of additional criteria requiring technical assessment but not directly derived from application of the reference documents (e.g., time to implementation) was also approved by the SF 21 Steering Committee. Appendix G discusses the Link Evaluation Criteria in further detail.

3.1 Technical Performance Criteria

For each of the operational enhancements in the Free Flight Operational Enhancements Document, the LET determined from the description of the operational enhancement whether requirements on the ADS-B/situational awareness link need be levied. If so, appropriate technical requirements in the ADS-B MASPS were identified as link evaluation criteria. After consideration of all the operational enhancements, all link-related ADS-B MASPS requirements were deemed applicable to this link evaluation; excerpts from the ADS-B MASPS which summarize these requirements are included within Appendix G of this document. For example, the operational enhancement entitled "Enhanced Operations for En-Route and Oceanic Air-to-Air" invoked ADS-B MASPS requirements such as "received ADS-B report update rate at 95 and 99 percent confidence".

Several of the operational enhancements require TIS-B and FIS-B in addition to ADS-B. The LET developed, with the assistance of the SF21 Steering Committee, data link information exchange requirements for these services to be applied to all three candidate ADS-B situational/awareness links. For TIS-B, for example, an 80-bit per target payload, to be uplinked for each target at a 5-second interval (the update rate for terminal area radars in the U.S.) was agreed to be used in each link evaluation scenario. For FIS-B, a datalink loading for evaluation purposes was developed based upon a prioritized listing of FIS-B information exchange needs provided by a cross-section of airspace user members of the SF21 Steering Committee.

3.2 Additional Implementation/Institutional Criteria Involving Technical Judgment

Additional link evaluation criteria are as follows:

- Time to implementation
  - Time to Availability of International Standards
  - Time to RF Spectrum Availability
  - Status of reduction to practice: Implementation Risk/Complexity
- Ability to Integrate and Interoperate with Existing Systems

Assessment of the link candidates against these criteria is made using a combination of modeling results and engineering judgment.

4. Technical Evaluation Approach

The primary objective of the technical evaluation of the ADS-B data link candidates is to characterize the performance of each link with respect to the technical performance criteria described in section 3.1. Link performance characterization is based on a modeling process, which uses laboratory bench and field/flight test data to validate, respectively, receiver performance and simulation models. The process and its inputs are illustrated in Figure 4-1.

The traffic scenarios and operational environment represent a series of assumptions regarding the disposition of aircraft and ground systems that must be considered in the link characterization. For example, the traffic scenarios dictate the number of aircraft in a given volume of airspace, their altitudes and their equipage. These assumptions are discussed in section 4.1.

The receiver/waveform model relates a signal, noise and co-channel interference level at the input to a receiver to a probability of successful message receipt. The simulation model invokes the receiver/waveform model to estimate the performance of the RF link between each pair of aircraft. The simulation model keeps track of aircraft (and their movement), estimates ranges and timing between communicating (or interfering) pairs of aircraft, generates the received signal and interference levels for the aircraft and maintains the measures of performance. The measures of performance can then be directly compared to the evaluation criteria to complete the link characterization. Both receiver and network models are discussed in section 4.2 while the test data used to validate the models are discussed in section 4.3. The LET believes that multipath will cause significant effects, especially on an airport surface. For practical reasons, the Team chose not to represent these effects in the simulations, but instead to evaluate them primarily through the use of test data.

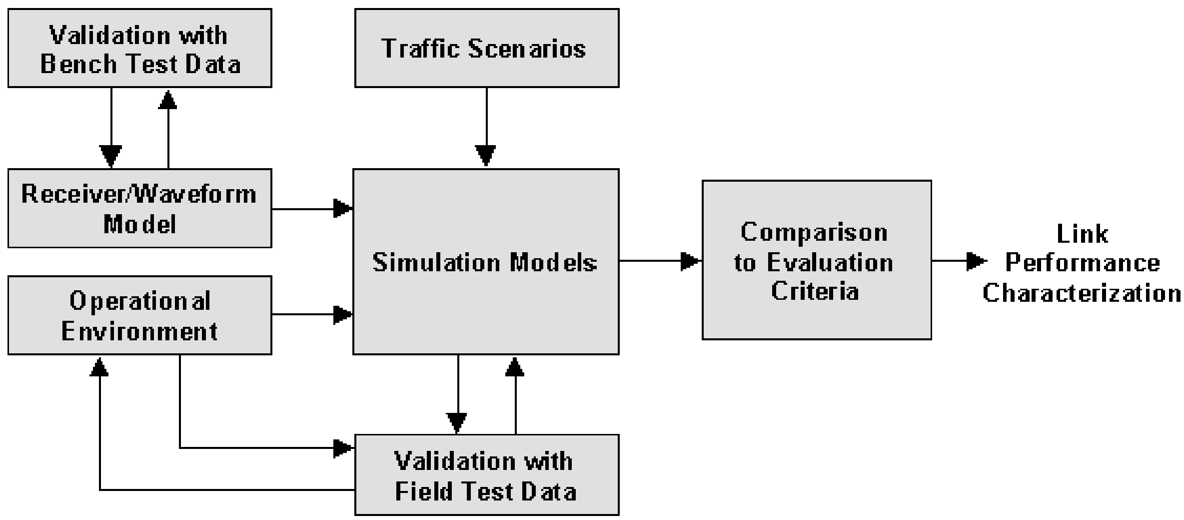


Figure 4-1: Technical Evaluation Approach Overview

4.1 Traffic Scenarios and Operational Environment Assumptions for Evaluation

The baseline assumptions for the link characterization have been divided into two categories: (1) air traffic scenarios and (2) operational environment. The traffic scenarios describe the physical distribution of aircraft that must be considered.

The LET has agreed on a total of five traffic scenarios to be used in its technical link evaluation. Table 4-1 introduces these traffic scenarios.

Scenario	Total Aircraft	Scenario Area
LA Basin 1999	1796 (including 150 on the ground)	400 nmi radius
LA Basin 2020	2694 (including 225 on the ground)	400 nmi radius
Core Europe 2005	838 (all airborne)	Square with 300 nmi sides
Core Europe 2015	2091 aircraft (both airborne and ground)	300 nmi radius
Low Density	340 (30 on the ground)	400 nmi radius

Table 4-1: Selected Traffic Scenarios

The LA Basin 1999 scenario has 787 airborne aircraft within the core area of 225 nmi and a further 859 airborne aircraft between 225-400 nmi. 314 aircraft lie within 60 nmi of the scenario's center (this includes aircraft on the ground). Around ten percent of the total number of aircraft are above 10000 ft in altitude. The LA Basin 2020 scenario was generated using exactly the same assumptions, with the aircraft densities increased by 50 percent.

The Core Europe 2005 scenario is focused around five major TMAs (Brussels, Amsterdam, London, Paris, and Frankfurt). Superimposed over the aircraft associated with each TMA is a set of airborne en route aircraft. The Core Europe 2015 scenario is also focused around the same five TMAs, with the aircraft distributions and assumptions taken directly from the Eurocontrol document entitled "High-Density 2015 European Traffic Distributions for Simulation," dated August 17, 1999.

The low density scenario is scaled from the LA Basin scenario. More complete details on all of the scenarios may be found in Appendix H.

The operational environment includes additional interference sources. These emitters include TIS-B and FIS-B ground stations which are assumed, for channel loading analysis, to be located in a hexagonal grid 60 nautical miles on a side. When representing the 1090 RF environment, fruit attributable to responses to ground and TCAS interrogations are included in the evaluation. In the cases of UAT and VDL Mode 4, this evaluation assumes that the channels are clear. Impacts of out-of-band emitters are not considered. More complete details on the operational environment may be found in Appendix I.

The coordinated measurements and simulations described above are comprehensive and include substantial parts not completed at this time of this report. As a result, performance assessments of the candidate systems have not yet been produced using this process. In the meantime, the LET has sought out sources of pre-existing information, including simulations and measurements, to provide an understanding of system performances for use at this time. A substantial body of information has been brought to light, as described in section 5.

4.2 Models

There are two types of models required to complete the link characterization: receiver/waveform and full-scale simulation.   There are three separate receiver/waveform models employed in the link evaluation, one for each link. All of the receiver/waveform models are based on bench test data taken by Johns Hopkins Applied Physics Laboratory (APL) on the UPS Aviation Technologies supplied radio equipment flown in the Ohio Valley SF21 Operational Evaluation. Bench test data provides the most accurate characterization of the actual link equipment; however, it also introduces the effects of specific implementation choices, which may not be generally representative of the radio performance once large scale deployment has occurred.   Therefore, the receiver/waveform models used in the link characterization have been designed to account for generalized implementations and thus have reduced the impact of certain implementation choices (e.g., signal acquisition process).

For each link's receiver/waveform model, there is a corresponding customized simulation model. Because of the links' differing designs, the simulation models for each link will be required to address somewhat different aspects of operation in order to focus on the issues that most critically affect performance. Table 4-2 lists the major set of functions collectively addressed by the simulation models and the links to which these functions are primarily applicable in order to assess performance adequately.

Functions	**Links for Which Function Is Applicable**
Traffic Distribution	All
Multiple Channel Management	VDL Mode 4
Pair-wise signal strength estimation (including LOS geometry, range, and antenna gain variations)	All
Co-channel (self) interference	All
Co-channel (other user) interference	Extended Squitter
Self-organizing slot selection logic	VDL Mode 4
Random Access	Extended Squitter, UAT

Table 4-2: Major Functions Addressed by Simulation Models

The Extended Squitter simulation model is planned to be based on a Volpe 1090 simulation effort, which has been geared towards the evaluation of the effects of ADS-B on a radar interrogator. However, preliminary discussions have been held with the model developers, and it appears that there is a good possibility that their simulation can be adapted to examine the effects of the 1090 MHz environment on ADS-B message reception.

The Swedish CAA has developed a simulation called STDMA/VDL Mode 4 Performance Simulator (SPS), and Eurocontrol has modified it to produce a version they call enhanced SPS. The purpose of this simulation is to model the VDL Mode 4 data link network management approach in order to evaluate its performance under a variety of conditions. This model has been made available for use, including source code, and could be modified to fill the need for simulation modeling of VDL Mode 4. Modification issues are currently being investigated, and it appears as if there is sufficient interest in producing a model which will be capable of meeting the modeling framework requirements.

APL has been developing a UAT simulation model for use in the data link evaluation effort. It is designed to include the variability in system parameters (e.g., antenna gain, cable losses, etc), and to accept as input the results of a receiver performance model, either using bench test data or theoretical waveform performance. This model also tracks message arrival times, accounting for the system determination of message transmit times and propagation delays, thus enabling interference to be specified in terms of arrival offset times as well as relative signal strengths. The aircraft motion is simulated as constant speed at present.

Appendix J provides further information on current and planned simulation and modeling efforts for the three candidate links.

4.3 Flight and Bench Test Data

During the course of this study, there has been a significant amount of data available to support model development and validation. The data has come from a number of field tests including the SF21 Operational and Technical Evaluations in the Ohio River Valley, follow-up VDL Mode 4 testing at the FAATC, and June 1999 LAX Extended Squitter interference tests. The data has also come from laboratory bench testing conducted by APL to characterize radio equipment performance and calibrate the equipment for field testing.

5. Technical Evaluation Status, Initial Findings, and Proposed Next Steps and Initial Findings

A discussion of technical evaluation status is followed by findings that the LET has reached. The initial findings (1) illustrate both technical strengths and technical weaknesses of the candidates; (2) provide inputs to aviation policy makers on what is known (no further technical analysis required) about the candidates; and (3) are intended to dispel misinformation (of which the LET must note there seems to be an ample supply) in the aviation community concerning ADS-B/situational awareness data links. The findings are followed by proposed next steps for link evaluation.

5.1 Evaluation Status

The LET completed system descriptions of each link candidate; developed link evaluation criteria for the operational enhancements identified in the Free Flight Operational Enhancements Document; agreed on a common set of traffic scenarios used in capacity simulations of the three link candidates; agreed on a simulation/modeling approach for link evaluation; participated in the collection of field data for each of the candidates and performed “quick look” analyses on much of that data; assessed simulation/modeling status for the candidates; bench tested and developed waveform models for two of the candidates (UAT and VDL Mode 4); and identified an approach to assure the completion of the corresponding bench testing for Extended Squitter.

Appendix J contains the LET’s assessment of the status of link models/simulations for the candidate links as well as simulation/model development needed to complete link evaluation. Modeling tools and simulations are discussed, for each candidate link, in terms of assessment of the RF link characteristics, modeling of candidate link performance in selected traffic distributions and traffic dynamics, evaluation of candidate link channel access and network protocols, and support for RF frequency planning. Each tool/simulation is briefly described, along with its planned use by the LET and any further development required.

Field data collected to date includes data from the SF21 Operational Evaluation (July 10, 1999), FAA Technical Center flight tests conducted through October 1999, data on Extended Squitter collected over Los Angeles in June 1999, and Eurocontrol flight tests performed in October 1999.

5.2 Initial Findings

The LET has agreed upon eleven initial findings. Each proposed finding was evaluated on the basis of three criteria:

a) Is the finding directly related to the technical link evaluation criteria?
b) Can the finding be fully supported by existing data (i.e., no further analysis required)?
c) Does the LET feel that the finding is important and should be of interest?

Proposed findings that met these criteria in the unanimous view of the LET are as follows:

1) Extensive information on and studies of 1090 Extended Squitter or related subjects exist, including reports on airborne and ground measurement activities. These reports have been reviewed in part by the LET, and will serve as resource material for further evaluation. A list of technical reports is provided at the end of Appendix C. The waveform, modulation, and message length defined in Appendix C have been the subject of live testing since the mid 1980’s. Beginning with the first flight tests of Extended Squitter in 1993, receivers have been under development to meet the requirements of ADS-B.

2) UAT has the simplest technical concept of the candidates. This simplicity, combined with use of well understood communications principles and UAT’s specification for operation on a clear channel, suggests that the necessary validation testing and standards development may be accomplished relatively expeditiously. Durations of standards development activities are observed to be difficult to predict.

3) Extensive information on and studies of VDL Mode 4 exist, including reports on airborne and ground measurement activities. These reports have been reviewed in part by the LET, and will serve as resource material for further evaluation. A list of technical reports and projects is attached in Appendix E.

4) The LET finds that there are important remaining efforts to complete equipment development and fielding (e.g., installation of new/replacement avionics and appropriate new ground-based

equipment), certification testing, application development, and other institutional issues that are in series with widespread ADS-B deployment, independent of link choice.

5) VDL Mode 4: The VDL Mode 4 system as described in Appendix E does not meet ADS-B MASPS state vector update requirements (which are applicable to all airspace domains) for Aid to Visual Acquisition and Conflict Avoidance and Collision Avoidance applications (from MASPS Table 3-4). Meeting these requirements in all airspace domains will require additional channel(s).

6) Extended Squitter: Improved 1090 MHz receivers (relative to existing TCAS receivers) will be needed to meet all ADS-B MASPS range and integrity requirements. Four such improved receiver designs were included in flight tests performed at Los Angeles in the summer of 1999. The LET is anxious to complete its review of this data (an interim report has been presented) and determine its applicability to Extended Squitter model validation.

7) UAT: Standards development has yet to be commenced, and there is no extensive validation experience via simulation or field measurement with the proposed modulation/waveform.

8) Spectrum status for Extended Squitter: The carrier frequency and bandwidth are specifically defined. Therefore, Extended Squitter is presently the only ADS-B candidate that has a permanent frequency assignment. No further spectrum support is required to authorize airborne transmission in the U.S. of Extended Squitters, at rates consistent with the 1090 MHz ADS-B MOPS. Further compatibility data/analysis is required to obtain authorization for ground transmission of Extended Squitter, TIS-B, and FIS-B as well as for co-installation of Extended Squitter avionics and ATCRBS transponders,

9) Spectrum status for UAT: Experimental use of 966 MHz, in the “target” 960-1215 MHz aeronautical radionavigation band, has been arranged within limited geographic areas of the U.S. U.S. action has been initiated to certify spectrum availability (probably not at 966 MHz) for further development of UAT. No such certification effort has yet been initiated at the international level. FAA Spectrum Management estimated that if the FAA decides to find a frequency for UAT, U.S. spectrum allocation for UAT can be accomplished within 6 months; international allocation was estimated to require at least 5 years after international consensus to deployment of UAT.

10) Spectrum status for VDL Mode 4: The Draft VDL Mode 4 SARPS require that transmit/receive applications should reside between 112-137 MHz and receive-only airborne applications (ground broadcast) should reside between 108-112 MHz. A frequency (136.950 MHz) has been arranged for VDL Mode 4 use within Europe, Malaysia, and Russia for experimental use. A second channel (136.900 MHz) has been arranged within Italy and neighboring states for experimental use. U.S. spectrum policy is that VDL Mode 4 implementation of ADS-B must be accomplished in the 108-118 MHz aeronautical radionavigation band. The allocation and authorization of the necessary frequencies for VDL Mode 4 in the U.S. will require time, but can be done.

11) Consideration of multipath is important in all phases of operation: air-to-air, air-to-ground, and on the airport surface, where multipath is most severe, particularly in the gate areas. Consistent with many years of experience with narrow band, digital, VHF data link on the airport surface, VDL Mode 4 is expected to exhibit more robustness to multipath on the surface, including the gate areas, than the other links. Experience indicates that the L-band links will support ATC surveillance in the surface movement area when configured with more antennas than needed in a VDL Mode 4 system.

5.3 Next Steps

Recommended next steps in the technical evaluation are:

1) Complete Extended Squitter bench test and waveform model definition;
2) Perform additional detailed simulation/model development;
3) Collect additional field data to further validate the link simulations;
4) Define necessity and scope of multipath testing for candidate links;
5) Develop procedures and define test configurations to measure received signal level and noise power in dBm during field measurements of UAT and VDL Mode 4;
6) Assess expected compliance to ADS-B MASPS and other defined requirements for each candidate using defined scenarios. Assessment will proceed using simulation, modeling results, and field data in comparison to normalized criteria and by examination of detailed simulation outputs of each received message;
7) Expand the link evaluation criteria as appropriate to support the ADS-B link decision process (e.g., applications that need to be supported but are not within SF21; consideration of technical aspects of multiple ADS-B/situational awareness links; any link-dependent criteria uncovered by ADS-B operational safety assessments; criteria for expandability and excess capacity);
8) Issue an updated Technical Link Evaluation Report.

As discussed in Appendix J, detailed link simulation/model development activities should focus on the completion of development of such models for Extended Squitter (by the Volpe Transportation Systems Center), UAT (by Johns Hopkins APL), and VDL Mode 4 (by APL and Eurocontrol). The LET will coordinate closely with these model developments and will further take advantage of other existing detailed models.

Additional field data will be collected in conjunction with the Cargo Airline Association, SF21 Program, and planned joint testing with Eurocontrol in 2000.

Expansion of the technical link evaluation criteria as appropriate to all aspects of ADS-B implementation is planned to take place as a next step in the FAA's ADS-B link decision process. The LET is of the view that the large majority of technical evaluation criteria have been captured from consideration of the SF21 Operational Enhancements.

Appendix A

Safe Flight 21 (SF21) Technical/Certification Subgroup
Link Evaluation Team

Terms of Reference

As Approved by SF21 Steering Committee on January 12, 1999

1. Produce a SF 21 Phase 1 Link Evaluation Report evaluating the suitability of three candidate ADS-B/situational awareness radio-frequency links: 1030/1090MHz, VDL Mode 4, and UAT. This Report, to the SF21 Steering Committee, should be produced within four months of the end of the SF 21 Phase 1 Operational Evaluation.

2. Develop, for SF21 Steering Committee approval, a set of link evaluation criteria derived from the stated SF21 applications, the RTCA ADS-B MASPS, and any further sources of requirements specified by the SF21 Steering Committee.

3. Coordinate with appropriate SF21 participants to provide inputs on the data gathering infrastructure, pertinent to link evaluation, to be provided for the SF 21 Phase I Operational Evaluation.

4. Generate a draft Statement of Work for a SF21 Phase I Link Data Gathering, Reduction, Analysis, and Link Simulation Contractor. Monitor the progress of and offer guidance to this contractor as requested by the FAA/SF 21 Steering Committee.

5. Participate as appropriate in link data gathering activities during the SF21 Phase I Operational Evaluation. As approved by the Steering Committee, perform analysis of link performance data as well as link simulations with respect to the link evaluation criteria approved by the SF21 Steering Committee.

6. Recommend, for SF 21 Steering Committee approval, any additional (to the SF21 Phase I Operational Evaluation) sources of actual link performance data to be used in developing the SF21 Phase I Link Evaluation Report.

7. Develop the SF21 Phase I Link Evaluation Report based upon the approved link evaluation criteria, the SF21 Phase I Operational Evaluation data and any other approved sources of actual link performance data, and the data reduction, analysis, and simulation tasks undertaken by the Link Data Gathering, Reduction, Analysis, and Link Simulation Contractor and the SF21 Phase I Link Evaluation Team.

Appendix B

Safe Flight 21 Technical/Certification Subgroup

Link Evaluation Team and Key Contributors

Link Evaluation Team

Richard Jennings, Co-Chair	FAA, Aircraft Certification
George Ligler, Co-Chair	PMEI/Rockwell-Collins
Lawrence Bachman	Johns Hopkins University APL
Tommy Bergstrom	SAAB Dynamics AB, EUROCAE Representative
Jonathan Bernays	MIT Lincoln Laboratory
Vincent Capezzuto	FAA, SF21 Product Team
William Harman	MIT Lincoln Laboratory
Stanley Jones	Mitre Corporation
Chris Moody	Mitre Corporation
Vincent Nguyen	FAA, Aircraft Certification
Johnny Nilsson	Swedavia, Chairman EUROCAE Working Group 51 (ADS-B), Subgroup 2 (VDL Mode 4 MOPS)
Thomas Pagano	FAA, William J. Hughes Technical Center
Robert Passman	FAA, Aircraft Certification
Ann Tedford	FAA, Architecture and System Engineering
Donald Willis	FAA, Spectrum Policy and Management
Raymond Yuan	Johns Hopkins University APL

Ex Officio:

Douglas Helton, Co-Chair SF21 Steering Committee	AOPA
Richard Lay, Co-Chair SF21 Steering Committee	FAA, SF21 Product Team
Edward Thomas, Co-Chair SF21 Ops/Procedures WG	United Airlines
William Blackmeir, Co-Chair SF21 Ops/Procedures WG	NATCA
William Flathers, Co-Chair SF21 Cost/Benefit WG	Sparrow-Tech
Robert Rovinksy, Co-Chair SF21 Cost/Benefit WG	FAA, Investment Analysis and Operations Research

Key Contributors

Costas Tamvaclis	Eurocontrol
Robert Darby	Eurocontrol
Pieter van der Kraan	Eurocontrol
Nick McFarlane	Eurocontrol
Gunnar Frisk	Swedish CAA
Donald Nellis	FAA, Spectrum Policy and Management
Kevin Parker	Johns Hopkins APL

The Link Evaluation Team further wishes to acknowledge important presentations made by the following additional individuals:

Robert Grove	UPS Aviation Technologies
Niclas Gustavsson	Swedish Civil Aviation Administration
Michael Geyer	Volpe Transportation System Center

The LET also thanks the many additional persons who have provided written inputs to the Team's deliberation and have assisted members of the Team in their analyses.

Appendix C

Extended Squitter System Description

System Proposed for Link Evaluation

This appendix is provides a concise description of the Extended Squitter system for ADS-B, to support the evaluation of three candidate links for ADS-B, as a part of the Safe Flight 21 program in 1999. In addition to the functions of ADS-B, the system described also includes capabilities for TIS-B (Traffic Information Service-Broadcast) and FIS-B (Flight Information Service-Broadcast).

The system description describes both the equipment tested in 1999 and the future operational system. Any differences are highlighted.

Contents

C.1 Basic System Characteristics

C.1.1 Multiple Access

Provisions for multiple aircraft to transmit ADS-B information and for multiple aircraft and ground stations to receive the information are based on pseudo random timing of the transmissions. Whereas each type of message is transmitted in a pattern that is nominally periodic with a standard rate (rates given in Section C.1.3.1), the transmission times are deviated slightly using a pseudo random process. Specifically, a timing jitter uniformly distributed over a range of +/-100 ms is applied to each transmission. This jitter is much larger than the duration of each message, so that synchronous interference effects are avoided. The net effect is a random probability of losing each reception due to the presence of signals received from other aircraft. The tests in 1999 are identical in this respect to the proposed operational system.

C.1.2 Waveform

C.1.2.1 Radio Carrier Frequency and Modulation

The carrier frequency, modulation, and other characteristics of the Extended Squitter waveform are all identical to the standards for Mode S transponder replies [ref. 2]. The main parameter values are summarized in the following sections.

C.1.2.1.1 Carrier Frequency

1090 MHz +/- 1 MHz.

C.1.2.1.2 Modulation

Pulse position modulation. For each bit period, a pulse is transmitted either in the first half of the period (indicating a 1) or the second half of the period (indicating a 0).

C.1.2.2 Data Rate

1 M bit / second, within a message, as illustrated in Figure C.1-1.

C.1.2.3 Message Synchronization

A transmitted message includes a preamble so that a receiver can detect the beginning of the message and can synchronize on the data in the message. The preamble consists of 4 pulses as shown in Figure C.1-1.

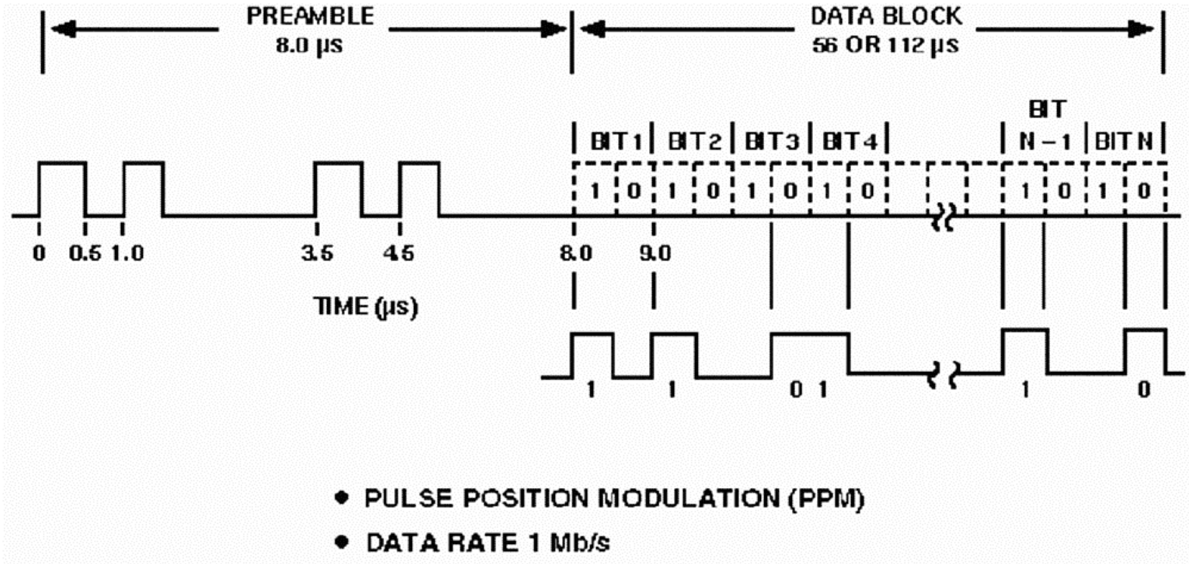


Figure C.1-1: Signal format, showing preamble and data block

C.1.2.4 Message Size and Coding

C.1.2.4.1 Message Size

A message consists of 112 bits (Figure C.1-1).

C.1.2.4.2 Coding

Each message contains 24 parity bits, which can be used for error detection or correction. This is the standard Mode S code, which is currently used by transponders, SSRs, and TCAS [ref. 2].

C.1.3 Messages and Reports

C.1.3.1 Message Types and Broadcast Rates

The basic position-velocity-time information is broadcast as follows. Position is broadcast in a "position message" transmitted at a rate of 2 per second. Velocity is broadcast in a "velocity message" transmitted at a rate of 2 per second. For each of these, the time of applicability is given as the time of transmission. Additional messages are transmitted as follows. Aircraft identity (a message transmitted once per 2.5 seconds), Intent type A (a message transmitted once per 1.7 seconds), Intent type B (a message transmitted once per 1.7 seconds), and a status message which is transmitted once per 1.7 seconds. Intent and status messages are transmitted only by some aircraft, which are equipped for certain functions as described in the MASPS [ref. 1].

When an ADS-B aircraft is on the airport surface, the system includes a provision to change to surface message formats and rates. This change is to be triggered automatically by a squat switch. The surface formats include higher-accuracy position information, and they omit altitude information and include velocity together with position in the same message. The transmission rate is 2 per second while moving and 0.2 per second when stationary.

For small aircraft not equipped with a squat switch, it is not permissible for the system to depend on a manual switch. As a result, the airborne message formats have been designed to provide sufficiently high-accuracy position information so that they can be useful if transmitted by an aircraft on the surface.

The tests in 1999 included surveillance (position, velocity, and time) and identity, but not intent. In one respect, the tests in 1999 differ from the proposed operational system: currently the transmission rate for aircraft identity is once per 5 seconds, whereas in the proposed operational system it is once per 2.5 seconds.

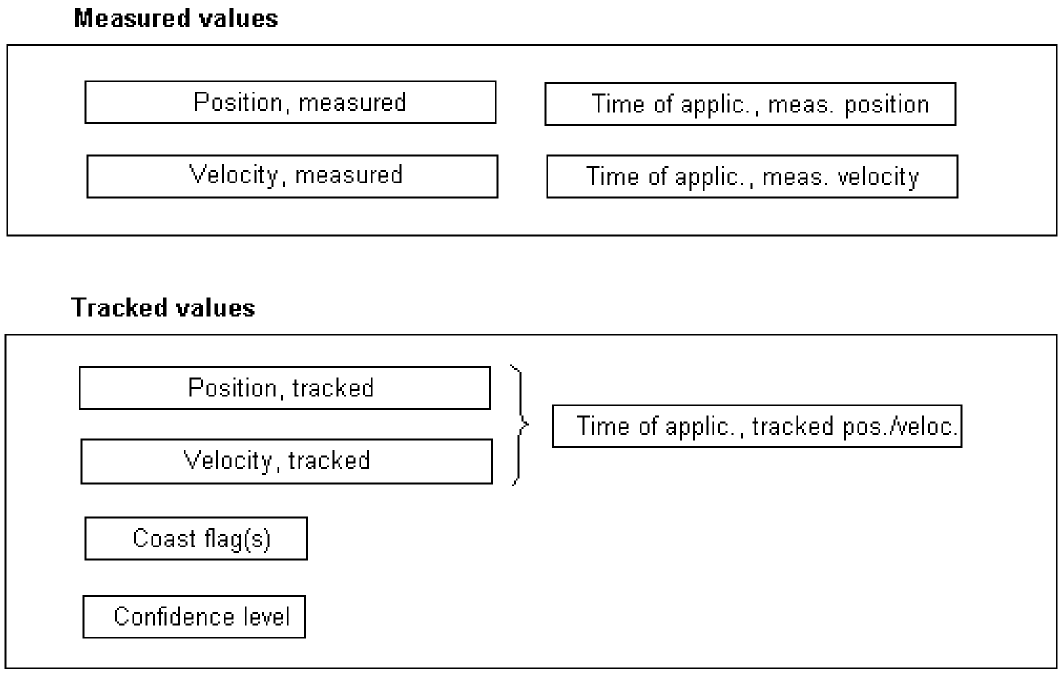
TIS-B information, to support see-and-avoid, can be transmitted from a ground station using data obtained from an SSR. In this case, TIS-B information is not transmitted for aircraft currently transmitting ADS-B information. Position and velocity are included in a single TIS-B message. Transmission rates for TIS-B and FIS-B are described in Sections C.6.1 and C.6.2.

C.1.3.2 Relationship Between Messages and Reports

Following the terminology defined in the MASPS [ref. 1], the term "message" is used to refer to one Extended Squitter of 112 bits, and the term "report" is used to refer to a block of information generated as an output by ADS-B for use as an input to "applications." In many respects, the information in a received message is reproduced directly into a report. There are several exceptions. Parity checking and error correction are done before generating reports. Therefore parity bits in the messages are not included in the reports. Another exception is latitude and longitude. In a message longitude is compressed into 17 bits, whereas in a report this is decompressed into a 24-bit format. The same is true for latitude. The data compression technique, called Compact Position Reporting or CPR, is described in more detail in Section C.3.1.1.

Another special case is time-of-applicability. In each message, the time of applicability is not transmitted digitally, but is conveyed as the time of transmission. In a corresponding report, however, time-of-applicability is reported digitally as an element of the report. Because position and velocity are transmitted separately, when they are combined into a report, two different times of applicability are reported. This is illustrated in Figure C.1-2. Furthermore, as shown in this figure, both measured and tracked values of position and velocity are given in reports. The measured values have different times of applicability, whereas tracking is used to generate values of position and velocity for a common time of applicability. As shown, the tracked values are accompanied by additional elements giving the confidence of the track and coast information. It is possible in some cases for an application to provide control information to the ADS-B avionics indicating that only one of the two types will be used (either measured values or tracked values). In that case the other type is not provided by Extended Squitter ADS-B to that application.

In most other respects the information in messages is conveyed directly into reports. Figure C.1-3 illustrates the relationship between messages and reports for the major information elements. This figure applies to normal airborne ADS-B transmission. As described in Section C.1.3.1, when an aircraft is on the airport surface, message formats for surface conditions are used. Position information is still transmitted in 17 bits for each component, but altitude is not included and velocity and position are together in one message [reference 3]. In addition, Mode S messages and formats have been designed to allow for other fields for special circumstances, such as when data of a particular type is not available [reference 3, Tables 2-11 and 2-16].



Note. All of these elements are provided in each state-vector report, unless inhibited by an application (see text).

Figure C.1-2: ADS-B reports of position-velocity-time

As described in Section C.6.1, TIS-B would use a message format including both position and velocity in the same message. More specifically, the message would contain latitude and longitude in 12 bits each (LSB = 120 m), velocity in 10 bits, altitude in 12 bits, and address in 24 bits, plus a 5 bit site ID.

C.1.4 Spectrum issues

C.1.4.1 Channel availability

Using Mode S Extended Squitter for ADS-B differs in this respect from the two alternatives. The two alternatives are being newly developed to meet the ADS-B standards in the MASPS, and as yet do not have specific channels designated for their operation. The concept for Mode S, however, is to use the existing Mode S signal format, including the RF channel, data rate, modulation, preamble, and all of the pulse shape and other standards that apply to the existing operational Mode S systems. Field measurements and simulation are used to assess the ability of this extension to existing Mode S formats to meet the MASPS standards for the various applications defined in the MASPS. Channel availability for Extended Squitter is dependent on the demonstrated compatibility with current approved systems operating in the 1090 MHz band. This issue has been addressed through work by the FAA Spectrum Office and the FAA TCAS development program beginning in 1994. This FAA work has two parts, (1) interference from the ADS-B transmissions to existing systems, and (2) interference effects on the performance of ADS-B, including self interference and interference from existing systems to ADS-B. The work is described in the following two sections.

REPORT ELEMENTS

MESSAGE TYPES	"State Vector"														"Mode Status"					"On-Condition"		
	ICAO address	Latitude	Longitude	Altitude (geo.)	NUC(p)	North velocity	East velocity	Vertical rate, geometric	NUC(R) velocity components	Altitude, baro	Baro. alt. rate	Air speed	Ground speed, ground track	Turn indication	Call Sign	TCP latitude	TCP longitude	TCP altitude	Emergency	TCP+1 latitude	TCP+1 longitude	TCP+1 altitude
Position squitter	24	17	17	12	5					12												
Velocity squitter	24			8		11*	11*	10	3		10	11*	22	2								
ID squitter	24														48							
Intent type A squitter	24															14	14	10				
Intent type B squitter	24																			14	14	10
Status squitter	24																		3			

Note 1. Entries indicate number of bits in a message.
Note 2. The 17 bits of latitude and 17 bits of longitude are compressed (Section C.3.1.1). The resulting reports are uncompressed to 24 bits each.
Note 3*. When airborne, normally velocity over the ground is transmitted. If velocity over the ground is not available, airspeed and heading are transmitted instead.
Note 4. Either barometric or geometric altitude is transmitted. The message indicates which form is being transmitted.

Figure C.1-3: Relationship between messages and reports

C.1.4.2 EMC Effects of ADS-B on Existing Systems

The initial technical work on this issue was an interference analysis by Lincoln Laboratory, which is documented in reference [4]. . Much additional work has also been done using a comprehensive simulation that was developed by the Joint Spectrum Center (JSC) during the TCAS development program and the Mode S development program before that. Many results have been generated during the course of this work. Currently interference conditions have been found to be quite small and acceptable. In some respects additional work is ongoing, focusing mainly on the effects of squitters from aircraft on the airport surface as received by an SSR located at the same airport. Initial field results indicate that such interference is not significant.

Not included in these studies are TIS-B, FIS-B, and co-installation of an ATCRBS transponder with a separate Extended Squitter unit, which are now being considered in this link evaluation. Initial interference assessments are given below in Sections C.6.1 and C.6.2.

C.1.4.3 EMC Effects on the performance of ADS-B

The other part of the spectrum approval process is a determination of the effectiveness of ADS-B as limited by existing systems and self interference. The initial work on this issue was a technical analysis by Lincoln Laboratory, which is documented in reference [5]. Recently this analysis has been extended by use of a track-level simulation at Lincoln Laboratory, whose results are being documented in the Extended Squitter MOPS, Appendix E [ref. 3]. Airborne tests in Los Angeles are providing additional validation information, and are particularly useful in that they provide an opportunity to experience air-to-air Extended Squitter signaling in a high density environment, including high rates of signals from existing systems (ATCRBS, Mode S, and TCAS), as well as multipath conditions and signal fading conditions caused by aircraft antenna patterns.

C.1.5 Differences Between the 1999 System and the Operational System

As stated in the beginning of this document, differences between the 1999 tests and the proposed operational system are of interest for every aspect of the system. Any differences are described explicitly item by item. To summarize all of the above information, there is a difference in the rate of transmitting aircraft ID information, as stated in Section C.1.3.1. In all other respects, the 1999 tests are consistent with the proposed operational system.

C.1.6 Power Parameters

C.1.6.1 Transmitter Power

The transmitter power levels for transmitted Extended Squitter signals are the same as the existing standards for Mode S transponders. Specifically:

Equipment Class	Transmitter Power (at ant.)
Normal	51 to 57 dBm
Low-end	48.5 to 57 dBm

These values are referred to the antenna end of a cable between the antenna and the ADS-B unit. Low-end values apply to aircraft limited in altitude to 15000 feet or below and limited in speed to 175 knots or less. Otherwise the normal values apply.

C.1.6.2 Receiver MTL

Receiver sensitivity is characterized by the Minimum Triggering Level (MTL). MTL is defined as the power level of a received signal for which correct reception is 90 percent reliable in the absence of interference. Standards for receiver MTL are divided into four classes, according to the classes defined in the ADS-B MASPS [1].

Equipment Class	MTL (at antenna)
A0	-74 dBm or lower
A1	-74 dBm or lower
A2	-79 dBm or lower
A3	-84 dBm or lower

These values are expressed with reference to the antenna end of a cable between the antenna and the ADS-B unit.

C.1.6.3 Summary of Basic System Characteristics

For convenience the basic system characteristics are summarized as follows.

	Proposed operational system	1999 tests
Frequency band	1090 MHz	same
Channels	one channel	same
Bit rate	1 Mb/s	same
Modulation	PPM	same
Synchronization	4 pulse preamble	same
Message length	112 bits	same
Parity	24 bits	same
Address	24 bits	same
Longitude	CPR, LSB ~ 5 meters 17 bits even, 17 bits odd	same
PVT segmentation	velocity in separate message	same
Transmitter power (at ant.)	51-57 dBm, normal 48.5-57 dBm, low end	
Rcvr. MTL (90%) (at ant.)	<=-84 dBm, high-end <=-74 dBm, low-end	same
Polarization	vertical	same
Transmission rate, PVT	2/sec. position 2/sec. velocity	same
Multiple access technique	random short messages	same

C.2 System Overview

C.2.1 Architecture Relating ADS-B with Navigation and Communications

C.2.1.1 Intended Surveillance Role

Extended Squitter does not differ from alternative ADS-B links in this respect.

C.2.1.2 Quality of Service

C.2.1.2.1 Availability and Continuity of Service

Extended Squitter does not differ from alternative ADS-B links in this respect.

C.2.1.2.2 Integrity

C.2.1.2.2.1 Report Validation

In the avionics configuration expected to be the most common, the ADS-B transmitting functions will be packaged together with Mode S transponder functions in a single unit. For air-to-air surveillance, a TCAS system can use direct interrogation-reply to measure the air-to-air range for comparison with ADS-B information, in order to validate ADS-B. This capability is viewed as important in TCAS, and has been developed as a standard mode of operation called Hybrid TCAS. Similarly, for surveillance of aircraft by a ground station, direct interrogation-reply can be used to measure the range of the aircraft for comparison with ADS-B information, in order to validate ADS-B. A system design may make use of validation by a ground station to support air-to-air surveillance. For example, an SSR at San Francisco airport could be used to check the validity of ADS-B data transmitted by landing aircraft, to support procedures based on air-to-air surveillance using ADS-B.

C.2.1.2.2.2 Probability of Undetected Message Error

This is controlled by the parity field included in each squitter, as described in Section C.1.2.4.2. Also, as described in Section C.2.2, when receiver sensitivity is enhanced to extend long-range performance, then a conservative form of error correction/detection should be used to keep undetected errors to a very low rate. Simulations indicate that this technique is effective is keeping the undetected error rate within the MASPS standards (1 x 10-6).

C.2.2 Transition From Current Systems to ADS-B

The concept of using the Mode S signal format for ADS-B was originally based on perceived advantages in transitioning from currently operating systems. Operational Mode S transponders currently transmit this waveform, so the avionics functions that generate the signal (including transmitter, modulator, etc.) could be used. Furthermore the proposed ADS-B power levels are also the same as the existing transponder power levels. Therefore a single unit can readily be used to implement both ADS-B transmission and Mode S transponder functions. Transitioning from a Mode S transponder to ADS-B transmission would be a small step. Manufacturers currently offer certified Mode S transponders that include this function.

Similarly, TCAS avionics currently receive the Mode S waveform. Therefore the experience gained through the design of avionics and operational use of TCAS would be expected to provide an extensive base from which to transition to ADS-B. A notable difference between TCAS reception and ADS-B reception is receiver sensitivity, which can be enhanced for ADS-B relative to TCAS to extend air-to-air range. The receiver MTL values given above (1.6.2) are enhanced in two of the four classes. An enhancement of receiver sensitivity should be accompanied by enhancements of Mode S reception techniques. This is because weaker signals are accompanied by higher rates of interference. At a minimum, a more conservative error correction technique must be used to prevent an excessive rate of undetected errors. Several other techniques for improved reception have been developed, as described in Section C.4.2.2.

C.2.3 A Useful Transition Path

It has been observed that a useful transition path can be followed using Mode S Extended Squitter. The concept is to use existing Mode S radars to elicit downlink messages containing the same information as in Extended Squitters. This can be done before ADS-B is operational, and can be used to build up experience with ADS data, originating in GPS, received onboard an aircraft, converted into Mode S messages, and conveyed to the ground in Mode S replies. Building up experience with this mode of operation will be useful in transitioning to future configurations in which confidence would ultimately be placed in ADS information.

C.3 Information Exchange

C.3.1 Broadcast Message Generation

C.3.1.1 Information Source Interface and Information Compression

In most respects, use of Extended Squitter for ADS-B would not differ from other possible links. For example, the normal source of position-velocity-time information would be a GPS receiver, but other sources are possible, and in any case the accuracy of the source is included in the messages.

As described above in Section C.1.4.1, the basic concept for Extended Squitter was to use an existing Mode S format, including message length of 112 bits. As a result it is necessary to encode position information efficiently to keep within the given message length. The form of data compression that has been developed for this purpose is called Compact Position Reporting, or CPR. The resulting messages are compact in the sense that several higher-order bits, which are normally constant for long periods of time, are not transmitted in every message. For example, in a direct binary representation of latitude, one bit would designate whether the aircraft is in the northern or southern hemisphere. This bit would remain constant for long periods of time. To repeatedly transmit this bit in every position message would be inefficient. Using CPR, a 23 bit latitude is compressed into a 17 bit message.

Because the higher-order bits are not transmitted, it follows that multiple locations on the earth will produce a particular encoded message. If only a single position message were received, the decoding would involve an ambiguity as to which of the multiple solutions is the correct location of the aircraft. The CPR technique includes a provision to enable a receiving system to unambiguously determine the location of the aircraft. This is done by encoding in two ways that differ slightly. The two formats, called even-format and odd-format, are each transmitted fifty percent of the time. Upon reception of both types within a short period of time (approximately 10 seconds), the receiving system can unambiguously determine the location of the aircraft. The multiple solutions from the even reception (which are spaced by at least 360 nmi) and the multiple solutions from the odd reception (similarly spaced) agree only at one point on the globe.

Once this process has been carried out and the receiving system has determined the location unambiguously, each subsequent single message reception from a moving aircraft is sufficient to unambiguously indicate the location of the aircraft. A simple track file is used to save the location of the aircraft for use in decoding subsequent receptions. When a target flies to long range and then disappears from coverage, its entry in the track file can be discarded. An appropriate time-out value is 200 seconds, which will be sufficient to retain the global solution for use after a temporary dropout.

C.3.1.2 Latitude-Longitude Quantization

Using Extended Squitter CPR the latitude-longitude quantization has a quantization accuracy of about 1.4 meters rms in the airborne format. The MASPS states that latitude-longitude accuracy can be as large as 20 meters rms [ref. 1, Table 3-4]. This applies to airborne aircraft. For aircraft on the surface, the inaccuracy should not exceed 2.5 meters rms [ibid.]. Therefore CPR in the airborne format provides sufficient accuracy for both airborne aircraft and aircraft on the surface. Extended Squitter was designed that way in order to allow for the fact that some low-end GA aircraft will not be equipped with a squat switch and will therefore always transmit the airborne format, even when on the surface.

C.3.2 Message Reception and Output Reports

C.3.2.1 Message Reception and Information Decompression

This is described in Sections C.1.3.2 and C.3.1.1.

C.3.2.2 Report Assembly

The relationship between messages and reports is described in Section C.1.3.2. Reports can be used by more than one application, and different applications can have different criteria for tracking, coasting, and dropping tracks. As described in Section C.3.1.1, within ADS-B a track file is used to decode latitude and longitude. The track file saves an initial even or odd position message in order to make the initial decoding of position when the other format is received. Similarly a decoded position is saved in the track file for use in decoding each new position message.

Reports are generated based on the following principles. No reports are issued until position has been determined using an even reception together with an odd reception. When an address is received for the first time, it is saved in the track file with the other information in the message plus a time stamp. A time-out is set up so that if no other messages are received to this address for 100 seconds it can be deleted from memory. As further messages are received having this address, they are checked to see if an even-position and an odd-position have been received within 10 seconds. When that happens, the location is computed and the first position report is issued, including all information available. Afterward, as each message is received, it is saved with a time stamp, and the previous message of that type is discarded.

C.3.3 Reports and Supported Applications

C.3.3.1 Output Report Format as Compared with the Format in the MASPS

ADS-B data in Extended Squitter messages are reported in the formats given in the MASPS [ref. 1], with one addition. As described in Section C.1.3.2, position and velocity are accompanied by the two different times of applicability.

C.3.3.2 Application Interface

Extended Squitter does not differ from alternative links in this respect.

C.3.3.3 User Adaptation Features

In some cases, an application may provide control signals back into the ADS-B system, to provide for special interface conditions. For example, as described in Section C.1.3.2, an application may provide a control signal to indicate that only one of the two report format, measured or tracked, will be used, and therefore the other need not be provided. Such configurations are optional.

C.4 Message Reception and Co-channel Interference

C.4.1 Interference Sources

C.4.1.1 TDMA Slot Overlap

Extended Squitter does not use slotting as a means of multiple access by a number of aircraft (ref., Section C.1.1.1).

C.4.1.2 Random Access Interference

Extended Squitter uses a random time multiple access technique for multiple access as described in Sections C.1.1.1, C.1.4.2, and C.1.4.3. Existing systems in the 1090 MHz band that constitute interference to ADS-B include SSR, military IFF, TCAS, and TACAN/DME. In recent years, live testing of Extended Squitter has been carried out at Logan Airport, Hanscom Field, in the Gulf of Mexico, in the Los Angeles Basin, and at Atlanta International Airport. These test programs have provided useful experience with the Extended Squitter concept in high density environments. Recently, additional detailed testing was carried out in the Los Angeles Basin to gain experience with Extended Squitter signals in the most challenging interference environment.

C.4.1.3 Multipath

For air-to-air transmissions, multipath caused by reflections from the ground or water over which the aircraft are flying are to be expected in many cases. These effects were a major factor during the development of TCAS. The live testing of Extended Squitter at Logan Airport and other locations has been quite useful in assessing the effects of multipath and other real-world phenomena. Field measurement results indicate that such interference is not expected to degrade the performance of 1090 Extended Squitter below that necessary to meet the ADS-B MASPS requirements.

C.4.1.4 Ownship Suppression Effects on Link Availability

In addition to the interference effects received from external sources, effects from ownship systems are to be considered. For an airborne Extended Squitter receiver, it may be appropriate to gate the receiver off when an Extended Squitter transmission is generated onboard, and also during SSR replies (in Mode A, Mode C, and Mode S). The receiver may also be gated off when an onboard TACAN or DME is transmitting. In these cases, it may be possible to leave the receiver on, relying on a limiter to protect the receiver front end from these strong signals. If the receiver is not gated off, the effect would normally be essentially the same, because a reception from another aircraft at a normal signal level would be overshadowed by the strength of a transmission from ownship. For an aircraft equipped with TCAS, similar conditions are to be expected. When TCAS transmits an interrogation of 1030 MHz, depending on the specifics of the installation, the effect in an Extended Squitter receiver at 1090 MHz may be so strong that no Extended Squitter receptions are possible at the same time. Similarly, in the reply period immediately after a TCAS Mode C interrogation, a large number of Mode C replies are normally received, and these would interfere with Extended Squitter receptions. After a TCAS Mode S interrogation, only one reply is expected, so Extended Squitter receptions may be received during this period, depending on the specifics of the avionics design. We note that the field measurements conducted recently in the Los Angeles Basin were performed with TCAS operational on several of the ADS-B receiving aircraft, and the operational effects of TCAS/ADS-B interaction are reflected in the results.

C.4.2 Decoder Responses

C.4.2.1 Synchronization

The Extended Squitter signal format begins with a 4-pulse preamble as described in Section C.1.2.3. When an Extended Squitter is received, a basic receiver synchronizes on the reception from the 4 pulse preamble.

Several techniques for improved reception have been developed, one of which is improved preamble detection. This technique makes use of the first five message bits together with the 4-pulse preamble. This “9-pulse preamble detection technique” is described in more detail in ref. [3], Appendix I.

C.4.2.2 Probability of Correct Reception

When an Extended Squitter is received in an environment including both interference and receiver noise, the probability of correct reception is a key performance measure. Much work has been done to evaluate performance under a variety of conditions. This is described above in Section C.1.4.3.

Several techniques have been developed for improving reception probability while keeping the undetected error rate very low. These techniques are particularly beneficial when receiving weak signals accompanied by high interference, which are the conditions of long-range air-to-air reception in a high density area. The techniques include (1) the “9-pulse preamble detection technique (ref., Section

C.4.2.1), (2) use of amplitude information for demodulating message bits and assigning confidence levels, and (3) a more conservative and more capable error correction technique. These techniques are described in more detail in the Extended Squitter MOPS [ref., 3], Appendix I.

When ADS-B and TCAS are both on the same aircraft, the TCAS signals will diminish ADS-B reception probability by some amount. The amount of this degradation can be estimated as follows. TCAS transmits interrogations in both Mode C and Mode S. A Mode C interrogation prevents Extended Squitter reception during the interrogation (22 microsec.) and during the following Mode C replies. The Mode C replies will occupy a time period determined by the power of the interrogation, the result being approximately 30 nmi in range or approximately 360 microsec. in time. The total time period of reduced squitter reception is therefore about 22 + 360 microsec. The squitter duration (120 microsec.) should be added to this to account for the fact that reception loss can occur at any point in the squitter signal. The rate of Mode C interrogations is 83 top plus 4 bottom = 87 interrogations per second (the large number being associated with the whisper-shout sequence, which is transmitted on each of four antenna beams). Therefore the reduction in reception probability is

(83 + 4)/sec. * (22 + 360 + 120)microsec. = 0.044 for Mode C

TCAS Mode S interrogations are transmitted at a rate determined by the number of Mode S aircraft under surveillance, as affected by the built-in Interference Limiting function. In a high density area, the rate can be as high as about 20 interrogations per sec. The interrogation duration is 18 microsec. The interrogation will elicit one reply, at some time during a period of about 360 microsec. Extended Squitter reception can continue during this reply period, with a reduction in reception probability of about 60/(360 + 60) = 0.18. Therefore the reduction in Extended Squitter reception probability caused by TCAS Mode S interrogations and replies is

(20/sec) * 420 microsec * 0.18 = 0.002 for Mode S

Adding these two effects, the total reduction is

Reduction due to Mode C	0.044
Reduction due to Mode S	0.002
Total reduction	0.046

This estimate applies to a design in which the Extended Squitter receiver is gated off during the Mode C interrogations and the following 30 nmi range band, but is otherwise on. It is also possible, in another design, to leave the receiver gated off during the entire Mode C interrogation whisper-shout period. Typically the whisper-shout interrogations are spaced by 2 ms, in which case the Mode C effect is

(83 + 4)/sec. * (2 ms) = 0.17 for Mode C

There is a significant difference between these two designs. Clearly it is significantly better to gate Extended Squitter reception off only during the active Mode C reply period.

C.4.2.3 Multipath Susceptibility

As described in Section C.4.1.3, this is a major subject. Although a presentation of multipath measurements, and estimates of the effects on performance would consist of a large amount of material, the system design in this respect is relatively simple. Extended Squitter messages are transmitted at a rate higher that the minimum rate at which ADS-B information is needed. Also, Extended Squitter transmissions alternate between top and bottom aircraft antennas, and Extended Squitter receivers use at least a top mounted antenna and preferably both top and bottom antennas.

C.5 Subsystem Block Diagrams

C.5.1 Avionics Configurations in the Proposed Operational System

Given that the Extended Squitter signal is identical except for message content with Mode S replies, it might be anticipated that Extended Squitter transmission would normally be combined with a Mode S transponder in one box. This is certainly reasonable, but it's also possible for ADS-B avionics to be separate from a Mode S transponder. Similarly, given that TCAS avionics includes functions for reception and demodulation of Mode S replies, it might be anticipated that Extended Squitter reception would normally be combined with TCAS functions in one box. This is certainly reasonable but it's also possible for ADS-B avionics to be separate from TCAS. Integration of ADS-B receive and transmit functions will be vendor-dependent; such integration is not expected to affect the performance of ADS-B via Extended Squitter, although various packaging configurations may have certain economic advantages to the users.

Considering other possible avionics configuration, we find that a large number of different combinations are possible, beginning with the fact that some ADS-B aircraft will have TCAS while others may not. In some cases the aircraft will be equipped with an SSR transponder, which is consistent with operation in most high-to-moderate density airspace today, although ADS-B does not require an SSR transponder. In some cases ADS-B may use two antennas, top and bottom, but a single-antenna configuration is also possible. If the configuration includes two ADS-B antennas, it is possible for the ADS-B to have one receiver that is switched between the two antennas, and alternatively it is possible to employ two receivers so that both antennas are continually monitored. When a transponder is included, this may be normal power transponder, or it might be a low-end transponder (Section C.1.6.1). Also the transponder may employ antenna diversity or not. If the configuration does not combine ADS-B reception and TCAS into a single unit, then ADS-B reception has its own antennas, and these can be implemented with preamplifiers, as was done in the 1999 test avionics. Antenna-mounted preamplifiers are intended to help achieve good receiver sensitivity, since they essentially eliminate the effects of antenna-to-receiver cable loss on system sensitivity. Altogether more than 20 different avionics configurations are possible.

When ADS-B and TCAS are combined into a single avionics unit, there is a significant difference between the two that must be observed. When receiver sensitivity is enhanced for ADS-B, it must not also be enhanced for TCAS (because of interference control effects that are important in TCAS). Therefore it is necessary in such configurations to have a dual-sensitivity receiver for 1090 receptions.

To focus on a smaller number of likely configurations, the Link Evaluation Team has identified a set of four primary cases, which are illustrated in Figure C.5-1.

C.5.1.1 Low-End GA Configuration (A0)

The lowest level of these four includes an ADS-B and a separate ATCRBS transponder. The ADS-B transmissions are made by the ADS-B unit, using the low-end power standards (Section C.1.6.1). This configuration corresponds to MASPS Class A0. As noted in C.1.4.2, possible interference between the ADS-B unit and the transponder has yet to be studied in detail.

A similar configuration not shown here is that in which the aircraft has ADS-B without any transponder. While this is an allowed configuration, it is judged by the LET to be unlikely to have widespread deployment. This configuration, because it lacks equipage with an SSR transponder and therefore will restrict operation to airspace where SSR transponder equipage is not mandatory, is considered to be one that is unlikely to see widespread deployment.

C.5.1.2 GA Configuration (A0)

As illustrated, the next level has a Mode S transponder. In this case, the ADS-B transmissions are made by the transponder. The Mode S transponder power conforms to the low-end power standards (Section C.1.6.1).

C.5.1.3 Basic IFR Configuration (A1)

The next higher level applies to MASPS Class A1, for basic IFR capability. It includes a diversity Mode S transponder, using the normal power level, and top-bottom transponder diversity. ADS-B reception also employs top-bottom antenna diversity. ADS-B employs the current reception techniques.

C.5.1.4 ADS-B and TCAS Configuration (A2 or A3)

The most capable configuration shown in Figure C.5-1 applies to Classes A2 and A3. It includes TCAS on the aircraft which can be either separate or combined with ADS-B in one unit. ADS-B employs the enhanced receptions techniques (Section C.4.2.2).

C.5.2 Avionics in 1999 Tests

The avionics developed for testing in 1999 include Extended Squitter transmission and reception. This equipment is consistent with the proposed operational system design in all respects with one exception: the transmission rate for aircraft ID is once per 5 seconds whereas in the proposed operational system the rate is once per 2.5 seconds.

Several avionics configurations are available for testing, the main one being different from all the four cases shown in Figure C.5-1. This avionics configuration was developed by UPS Aviation Technologies. Antenna-mounted preamplifiers are included. A dual-channel receiver is also included, for continuous reception from both top and bottom antennas. The receiver is very sensitive, and conforms to the Class A3 sensitivity standards (Section C.1.6.2).

Other avionics that is available for testing include a Honeywell TCAS 2000, in which normal TCAS functions are combined with ADS-B, a general-purpose data acquisition system developed by Lincoln Laboratory (the 1090 MHz Test Bed), and a similar general-purpose data acquisition system developed by the FAA Technical Center (called DATAS). Data recorded by the 1090 MHz Test Bed is processed to provide either a non-real-time implementations of normal TCAS reception techniques, or the enhanced reception techniques described above in Section C.4.2.2. The Test Bed data is also used to make measurements of the interference environment during the tests.

C.5.3 Ground Stations in the Proposed Operational System

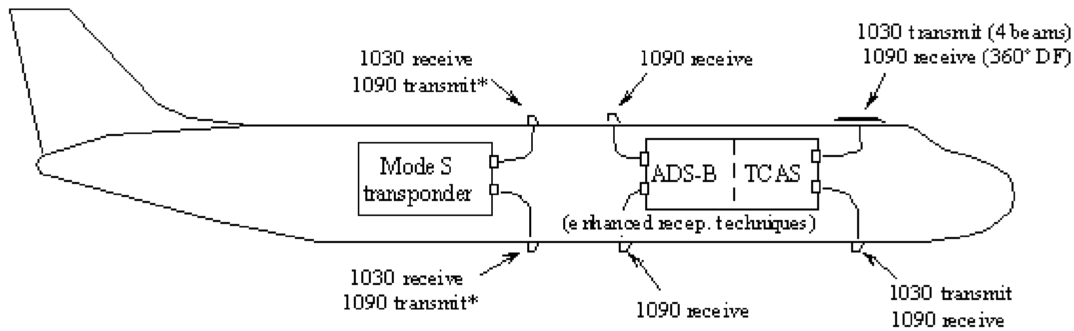
ADS-B using Mode S Extended Squitters can operate to some extent without ground stations. Ground stations can be used in order to provide surveillance information to ground based ATC systems. Ground stations can also be an important part of a system, providing redundant information for validation purposes. The ADS-B MOPS [ref. 3] addresses the issues of ground stations by including an appendix (Appendix D), written by the FAA, that states assumptions about the way the ground environment will evolve as a part of the ADS-B system. This appendix defines several levels of possible ground stations, beginning with a minimum level that performs 1090 MHz reception without 1030 MHz transmission. At the other extreme, a ground configuration is defined that includes 1030 MHz transmissions (to interrogate Mode S transponders and make direct range measurement for cross checking with ADS-B information). The maximum station also includes a multi-sector antenna, feeding multiple receiver channels. The transmitter is a one-channel transmitter, connected through an RF combiner to form an omnidirectional transmit pattern. The maximum station also includes multilateration functions which use receptions from multiple ground stations to determine the locations of aircraft passively using multilateration. A multilateration solution is useful for validation of ADS-B information and also for performing surveillance for aircraft not equipped with ADS-B.

Figure C.5-2 shows a block diagram for a ground station, based on material in reference [3], except extended to include TIS-B and FIS-B for purposes of this study.

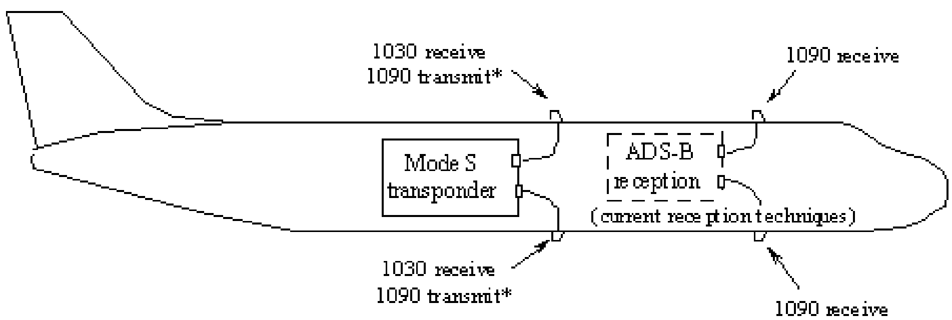
For surveillance of aircraft on the airport surface, an ADS-B receiving station will include a number of simple receivers. Because of the multipath environment at most airports, and obstructions by buildings, a single receiving antenna would not be sufficient to cover the full airport. It has been shown through testing at Logan Airport that approximately four receiving antennas are appropriate for an airport of that size. In the Logan tests, four receiving antennas provided effective coverage of the entire airport movements area. Coverage in the gate areas is more difficult, due to the congested structures of buildings and aircraft, and for that reason was not evaluated at Logan.

When a receiving system for airport surface surveillance is developed, it would be possible that a passive multilateration mode would also be included, for both validation of ADS-B information and for surveillance of aircraft not equipped with ADS-B.

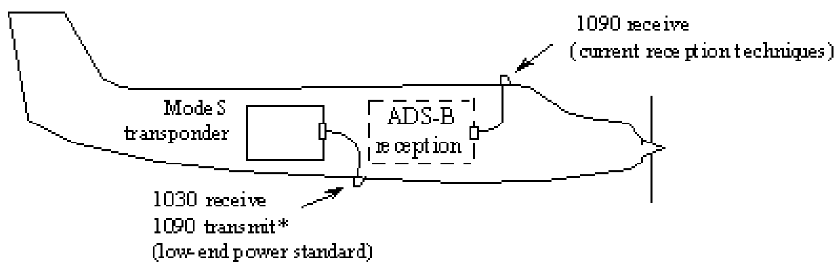
(a) ADS-B and TCAS (Class A2 or A3)



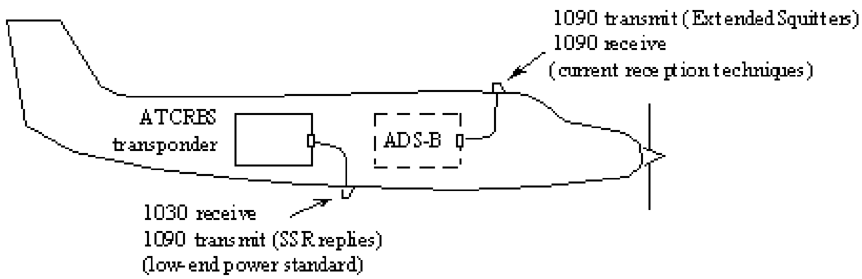
(b) Basic IFR Configuration (Class A1)



(c) GA Configuration (Class A0)



(d) Low-end GA Configuration (Class A0)



* These 1090 transmissions include SSR replies and squitters.

Figure C.5-1: Basic avionics configurations for Extended Squitter

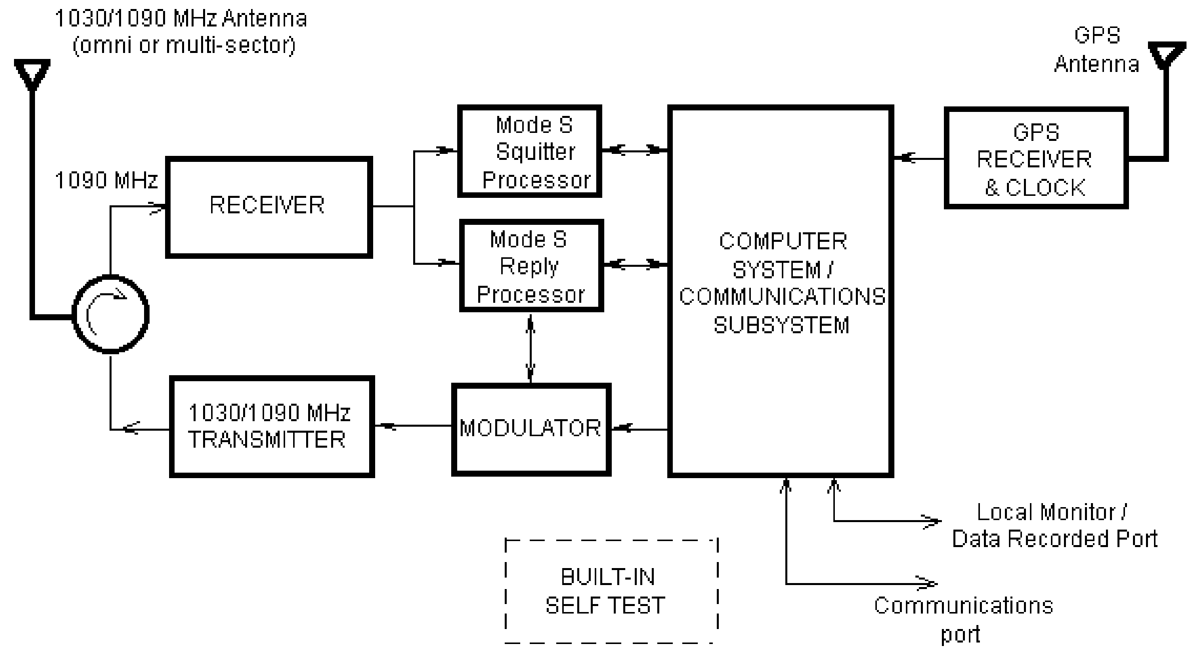


Figure C.5-2: Block diagram for an Extended Squitter ground station

C.5.4 Ground Based Equipment in the 1999 Tests

The ground based equipment developed for the 1999 tests is consistent with the proposed operational system in regard to waveforms and reception processing. This was not a complete system including TIS-B and FIS-B and interrogation/reply, but it included many facilities and enabled the testing of a number of aspects of the system. For example, instead of TIS-B and FIS-B messages, the ground based equipment simply transmitted Extended Squitters in the position and identity formats. The test system was also limited in having just two receiver channels instead of six. Transmission of Extended Squitters from the ground made use of a Mode S transponder as the signal source.

For testing in the Los Angeles Basin, the ground equipment included both a six-sector antenna and an omnidirectional antenna. These were used in several different configurations. In some cases, reception was via the sector antenna, using just two of the sectors, while Extended Squitters were transmitted via the omnidirectional antenna. In other cases both transmissions and receptions were done in the same antenna sector. The underlying purpose of these tests involving ground equipment was to gain experience with air-to-ground and ground-to-air transmission and reception in a dense interference environment.

C.5.5 Proposed Equipage Classes

Defined equipage classes for Extended Squitter are given in the MASPS.

C.6 TIS and FIS

C.6.1 TIS and TIS-B Description

For cases in which an ADS-B aircraft is equipped with a Mode S transponder, a basic form of Traffic Information Service (TIS) has been developed using the Mode S data link. Position messages are transmitted to the aircraft from a Mode S ground station, using the data block in Mode S interrogations. In addition to the interrogation(s) used for surveillance, up to three additional interrogations may be transmitted to supply the TIS information when necessary. This application has completed operational test and evaluation by the FAA Technical Center, RTCA has issued MOPS (DO-239) for avionics implementation, definition of TIS is included in the ICAO Manual of Mode S Specific Services, and terminal Mode S radars having the TIS function are deployed nationwide.

An extension of Extended Squitter to provide a broadcast form of TIS (called TIS-B) has been proposed for purposes of the Safe Flight 21 link comparison. In this concept, TIS information would be broadcast from the ground, using formats similar to Extended Squitter, based on surveillance information obtained from an SSR. This service is intended to support the application of enhanced see-and-avoid in the cockpit. TIS-B information is not transmitted for aircraft currently transmitting ADS-B information. Position and velocity are included in a single TIS-B message.

The rate and power of TIS-B transmissions can be estimated for purposes of the current study, whereas these are important system parameters whose final values would be determined in a more comprehensive development program. The TIS-B transmission rate is determined by the objective of providing reliable reception once per SSR scan (4.7 seconds). In considering interference, the TIS-B transmissions for a given non-ADS-B aircraft under surveillance can be compared with the corresponding ADS-B transmissions that would be transmitted by that same aircraft if it were ADS-B equipped, namely 4.2 squitters per second. This rate equals 19 squitters/scan. That rate is more than sufficient for reliable reception. Therefore a serviceable estimate of the TIS-B transmission rate is 2 per second (which equals 9 per radar scan) for each aircraft represented by TIS-B. This rate is approximately half the normal per aircraft ADS-B transmission rate. For transmitter power, a serviceable estimate for the current study is 500 watts referred to the antenna. This is somewhat higher than the normal power level for a transponder. This value is intended to keep interference effects very small, considering the overlapping of signals that would be expected if TIS-B were deployed in an area-wide configuration.

C.6.2 FIS and FIS-B Description

Similarly, Flight Information Services (FIS) can be transmitted to aircraft using Mode S signals. FIS information may include weather advisories, weather maps, ATIS, PIREPS, and SUA reports. A form of FIS included as a part of Mode S surveillance of aircraft from SSR ground stations has been developed by the FAA and tested extensively in recent years. In this service, the FIS information is transmitted to aircraft using Mode S interrogations in the 1030 MHz band.

An extension of Extended Squitter to provide a broadcast form of FIS (called FIS-B) has been proposed for purposes of the Safe Flight 21 link comparison. In this concept, FIS information would be broadcast from the ground. Data rate analysis by the Link Evaluation Team has concluded that an effective amount of FIS-B information can be conveyed with a data rate of 100 bits/sec. This rate refers to the information delivered, not including any parity transmitted for integrity reasons, nor any repeated transmissions intended to increase reliability.

For purposes of the link comparison, the following specifics of an FIS-B design using Extended Squitter are proposed. This design is sized to deliver a data rate of 200 bits/sec. (double the nominal data rate cited by the Link Evaluation Team). The rate of transmitting Extended Squitters from an FIS-B ground station is up to 50 squitters per second. Each squitter includes 80 bits of information, beyond parity, address, and control fields. Therefore a transmission rate of 50 squitters/sec. includes a total information rate of 50 * 80 b/s = 4000 bits/sec. This exceeds the delivered data rate (200 bits/sec.) by a factor of 20:1. This is a conservative margin, which provides assurance that the FIS-B information is delivered reliably at the designed rate. Transmitter power level is 500 watts referred to the antenna.

C.7 Growth Potential

Beginning in 1992, Extended Squitter was developed based on a concept that it would be appropriate for equipage by all aircraft, and that the density of aircraft will likely increase in the future. As use of the system grows, it is to be expected that signal rates from existing systems will be reduced, partially as a result of Hybrid TCAS, partly as a result of an on-going transition from ATCRBS to Mode S, partly as a result of upgrading some SSRs from the older beam-splitting technology to monopulse technology, and also partly as a result of the success of ADS-B providing a basis for discontinuing operation of some SSRs.

The P4 Suppression Workaround is currently being used at operational Mode S radars, as a means of dealing with a class of transponders (some of which were manufactured by Terra Corp.) that do not reply to the ATCRBS/Mode S All-Call interrogation format. This is viewed as an undesirable condition, and steps are begin taken to replace or modify these transponders. Using the P4 Suppression Workaround, an SSR transmits ATCRBS interrogations in order to perform surveillance on these few aircraft. This fix has the undesirable consequence of eliciting ATCRBS replies from Mode S aircraft, which consequently are under dual surveillance at all times. The FAA is taking steps to eliminate the defective transponders from the airspace and phase out the P4 Suppression Workaround for several reasons. One is that it prevents Mode S SSRs from operating efficiently in the mode in which they were designed; they elicit more replies than needed, which contributes interference to the 1090 MHz band. Also, the defective transponders are invisible to TCAS, which could be a serious problem in some cases. Therefore these transponders should be upgraded as soon as possible. As the P4 Suppression Workaround is eventually phased out, this too will result in a reduction of interference in the 1090 MHz band.

There is also a significant trend in which SSR Mode A and C interrogation rates have been decreasing over many years. This has been observed in airborne measurements beginning in the 1070s and continuing in the 1980s and 1990s. The improvements is attributed mainly to a continuing FAA program of frequency management. This program includes identification of SSRs operating without Sidelobe Suppression, SSRs operating at excessively high power levels, and SSR testers operated omnidirectionally, at high power levels, and high interrogation rates.

Considering both the growth in number of aircraft and the trends of decreasing transmission rates per aircraft, it might be reasonable to expect that the conditions of maximum interference in the 1090 MHz band are currently being experienced. Airborne testing in 1999 is particularly valuable, especially for tests done in high density metropolitan areas such as New York and Los Angeles.

C.8 Pre-Existing Evaluation Information

Prior to the work of the Link Evaluation Team, an extensive amount of information about Extended Squitter design and performance had been developed. The FAA began the development of Extended Squitter in the early 1990s, and there followed a program that has included flight tests, bench tests, and simulations at the pulse level, and at the track level. Most of the resulting information has been documented in technical reports. This body of pre-existing information is summarized in the following.

C.8.1 System Concept

The initial work was focused in the documentation of the system concept in 1993 [ref. 6]. This technical report also identified key issues for development work, and presented a first-order analysis of each issue and its resolution.

The First Airborne Tests were in 1993, in eastern Massachusetts. These were followed by testing on the airport surface at Hanscom Field and Logan Airport. This work is summarized in a video tape that describes the system concept of Extended Squitter and summarizes the measured reliability of surveillance on the airport surface. Reliable surveillance over the full airport surface was achieved by using four receiving antennas.

C.8.2 Gulf of Mexico

A program of tests over the Gulf of Mexico was conducted in 1994. These tests focused on low altitude flights over water, and in surveillance of helicopters by reception on antennas mounted on oil rigs in the Gulf. Long range surveillance over water was also tested. This work is documented in ref. 7.

C.8.3 Six-Sector Antenna

For reception at a ground station, the system concept includes a multi-sector antenna as a means of achieving long-range surveillance and tolerating interference. The initial analysis was extended by designing and procuring a six-sector antenna. This antenna was tested, first at an antenna range, and then on a tower receiving Mode S signals from airborne aircraft. This work is documented in ref. 8. Specifications and antenna performance characteristics for a commercial unit are summarized in ref. 18.

C.8.4 Atlanta Tests

Tests were conducted at Atlanta airport focusing on multilateration using Mode S short squitters, ATCRBS replies, and Extended Squitters. The results are documented in ref. 9.

C.8.5 Interference

Tolerating interference from ATCRBS fruit was an issue identified in the original system concept report. A more detailed analysis of interference effects was conducted and documented in 1995 [ref.4].

A more detailed simulation of interference conditions has been conducted by the Joint Spectrum Center (JSC). This work was sponsored by the FAA to assess interference that would be caused by transmission of Extended Squitters to existing systems. Based on these results, which are documented in ref. 10, the FAA has accepted the airborne transmission of Extended Squitters.

C.8.6 Capacity

System capacity, in the form of the maximum number of aircraft that could participate in the Extended Squitter system was analyzed in more detail and documented in a technical report in 1994 [ref. 5].

C.8.7 Low-Noise Receiver

The original system concept document also identified receiver sensitivity as an issue. This issue was examined in more detail in 1996, through receiver bench tests and corresponding analysis. The results are documented in ref. 11.

C.8.8 Airborne Reception

Airborne tests focusing on long-range air-to-air reception using a low-noise receiver were conducted in 1996 in eastern Massachusetts. The results are documented in ref. 12.

C.8.9 Interrogation Rate Measurements

Airborne measurements of interrogation rates in the 1030 MHz band were conducted in 1994 including Boston, New York, Philadelphia, Baltimore, Washington DC, Atlanta, and Dallas-Fort Worth. These are follow-on to previous measurements made in the 1970s and in the 1980s, and are interesting in that a significant decrease in rates has become evident. The measured rates are documented in ref. 13.

C.8.10 Reply Rate Measurements

Similar measurements of reply rates received airborne with an omnidirectional antenna were also conducted in 1994 and 1995. The measurements were made in all of the same locations as above and also in the Los Angeles Basin. The measured rates are documented in ref. 14.

C.8.11 Reception Techniques

It was recognized during the Extended Squitter development program that the interference conditions are significantly more severe in long-range air-to-air Extended Squitter reception than in TCAS. This is a consequence of the improved receiver sensitivity and ability to receive weaker signals. Such signals are accompanied by higher rates of interference. Enhanced reception techniques were developed to improve reception performance under these conditions. The techniques include (a) improved preamble detection, making use of the first five information bits together with the 4 pulse preamble, (b) improved demodulation, making use of the pattern of received power levels within each bit time interval, and (c) improved error correction, that is both more conservative, to keep the undetected error rate very low, and also more aggressive in correcting receptions having multiple errors. This development was done mainly with a pulse-level simulation, which is documented along with the major results in ref. 15. The simulation work was subsequently tested by air-to-ground testing in the Boston area, and then air-to-air testing in the Los Angeles Basin.

C.8.12 Long-Range Performance

After the ADS-B MASPS was completed in 1998, an assessment of air-to-air Extended Squitter performance was conducted for comparison with the MASPS standards. This assessment is in the form of a track-level simulation that includes even-odd position format alternation, top-bottom antenna alternation, correlation of signal power levels from message to message, deviations in received power caused by aircraft antenna gains, and similar phenomena to faithfully represent the actual air-to-air conditions. The formulation of the simulation is documented in ref. 16, along with simulation results showing system performance as compared with the MASPS standards.

C.8.13 Los Angeles Basin

The FAA conducted a major program of airborne testing in the Los Angeles Basin in June 1999, following a preliminary test mission a year before. These tests were mainly aimed at assessing air-to-air reliability of Extended Squitter in a maximum interference environment. Several different aircraft were involved and several different types of reception avionics were used. A ground station was also included, so that air-to-ground performance could also be tested as well as limited tests of ground-to-air transmissions. The results have been documented in a preliminary report [ref. 17].

C.9 References

[1] "Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B)", RTCA/DO-242, Feb. 1998.

[2] "Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/Mode S) Airborne Equipment," RTCA/DO-181B, 1999.

[3] "Minimum Operational Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B) Extended Squitter Airborne Equipment," RTCA SC-186, WG-3, draft, May 1999.

[4] V. A. Orlando and W. H. Harman, "GPS-Squitter Interference Analysis," MIT Lincoln Laboratory project report ATC-229, April 1995.

[5] V. A. Orlando and W. H. Harman, "GPS-Squitter Capacity Analysis," MIT Lincoln Laboratory project report ATC-214, May 1994.

[6] V.A. Orlando, "ADS-Mode S: Initial System Description," Lincoln Laboratory Project Report ATC-200, April 1993.

[7] R. Boisvert et al, "GPS-Squitter Automatic Dependent Surveillance Broadcast: Flight Testing in the Gulf of Mexico," Lincoln Laboratory technical report ATC-235, Oct. 1995.

[8] M.L. Burrows, "Six-Sector Antenna for the GPS-Squitter En-Route Ground Station, Lincoln Laboratory technical report ATC-248, May 1996.

[9] M. L. Wood and R. W. Bush, "Multilateration on Mode S and ATCRBS Signals at Atlanta's Hartsfield Airport," Lincoln Laboratory technical report ATC-260, Jan. 1998.

[10] R. Clarke, et al, "ADS-B Extended Squitter Interference Analysis," JSC draft report, Sept. 1998.

[11] W. H. Harman, et al, "Cockpit Display of Traffic Information (CDTI): Feasibility of Long Range Air-to-Air Surveillance," Lincoln Laboratory technical report 42PM-Squitter-0007, Oct. 1996.

[12] K.W. Saunders and R. A. Hogaboom, "Cockpit Display of Traffic Information (CDTI): The Long Range CDTI Experiment on Air-Air Surveillance Using GPS-Squitter," Lincoln Laboratory technical report 42PM-Squitter-0010, Dec. 1996.

[13] W. H. Harman and M. J. Brennan, "Beacon Radar and TCAS Interrogation Rates: Airborne Measurements in the 1030 MHz Band," Lincoln Laboratory technical report ATC-239, May 1996.

[14] W. H. Harman and M. J. Brennan, "Beacon Radar and TCAS Reply Rates: Airborne Measurements in the 1090 MHz Band," Lincoln Laboratory technical report ATC-256, January 1997.

[15] W. Harman, et al, "Techniques for Improved Reception of 1090 MHz ADS-B Signals," DASC Conference Proceedings, Oct. 1998.

[16] "Extended Squitter System Operation and Performance," MOPS for Extended Squitter ADS-B, Appendix E, draft, Nov. 1999.

[17] "Measurements In the Los Angeles Basin of Extended Squitter Performance, Interim Report," FAA, 29 October 1999.

[18] "Technical Handbook: Six-Sector Squitter-Ground-Station Antenna", dB Systems Model Number dBS 530, 28 February 1995

Appendix D

System Description for the Universal Access Transceiver

System Proposed for Link Evaluation of the Safe Flight-21 Applications[D1]

Chris Moody

October 1999

This document provides a description of the Universal Access Transceiver (UAT). This document will be used as part of the FAA's Safe Flight 21 project to evaluate candidate broadcast data links to support situational awareness functions.

[D1] Based on agreed outline within the Tech/Cert subgroup

Contents

D.1 Basic System Characteristics

D.1.1 Net Access Protocol

D.1.1.1 Net Management Concept

D.1.1.1.1 Timing of ADS-B and Ground Message Transmissions

Figure 1-1 illustrates the timing structure for UAT message transmissions. In the UAT system, the frame is the most fundamental time unit. Frames are one second long and begin at the start of each UTC (or GPS) second. Each frame is divided into two segments: one segment in which ground message burst transmissions may occur, and another in which ADS-B message burst transmissions may occur.

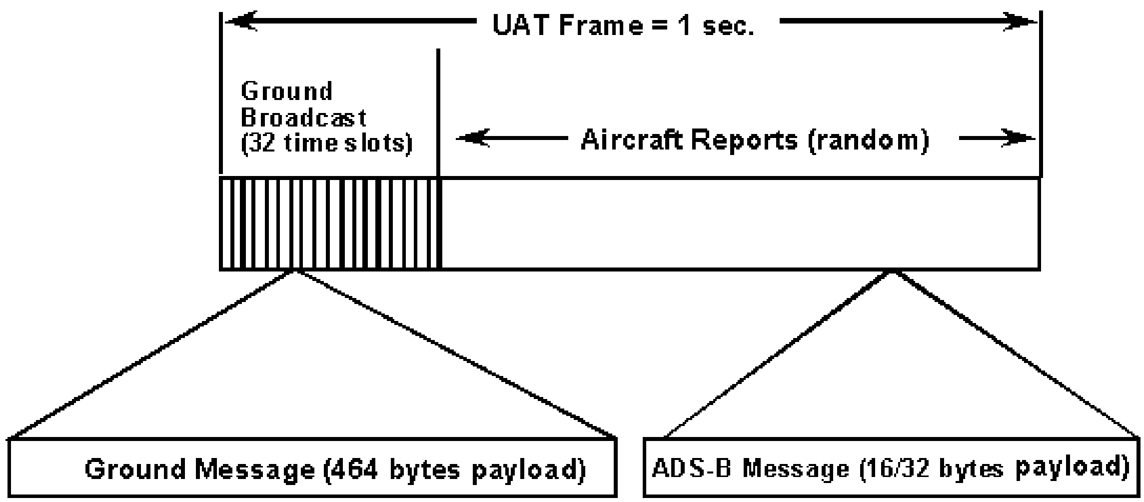


Figure D.1-1: UAT Timing Structure

Each segment is further subdivided into message start opportunities (MSOs) spaced 250 µs apart for a total of 4,000 MSOs per frame. The MSO is the smallest time increment used for scheduling ground message or ADS-B message transmissions.

NOTE: This allows a single fixed tuned airborne transceiver to support full air-air, ground-air, and air-ground connectivity for broadcast applications.

D.1.1.1.2 Scheduling of Ground Broadcast Message Transmissions

The ground broadcast segment consists of 752 MSOs, for a total of 188 ms. These 752 MSOs are divided into 32 ground broadcast slots, each 22 MSOs long, plus a guard interval of 48 MSOs (12 ms). Each ground station is assigned one of the 32 time slots, in such a way that nearby ground stations in range can always be received without interference. Each ground station transmits a ground broadcast message once each second, starting at the start of its assigned slot. Figure D.1-2 shows details of the MSO-based timing.

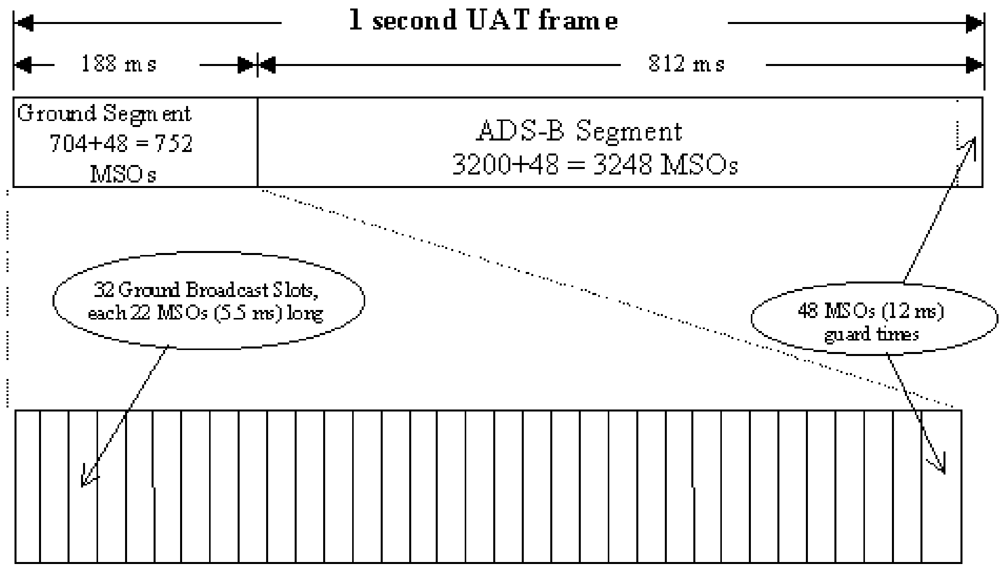


Figure D.1-2: Detailed View of MSO-Based Timing

A ground broadcast message burst occupies 4196 bit intervals, or 4.028 ms, and each slot is 5.5 ms long. Therefore a 1.47 ms gap remains before the start of the next slot. This gap is long enough for the transmission, travelling at the speed of light, to cover 235 nautical miles before the time arrives for the next ground station to transmit its burst.

D.1.1.1.3 Scheduling of ADS-B message transmissions

Although ground stations are each assigned their own fixed transmission slots in the first 188 ms of each one-second UAT frame, aircraft and surface vehicles have to share the ADS-B segment - the last 812 ms of each one-second frame. An A/V (aircraft or surface vehicle) is required to transmit at randomly selected times from among the first 3200 MSOs in the ADS-B segment of the one-second UAT time frames. This random selection is intended to prevent two aircraft from repeatedly interfering with each other's ADS-B message transmissions. Note that a substantial guard time--specifically for timing drift--is accommodated at both the beginning and end of ADS-B segment. This could accommodate clock drift in airborne units for a period of time before there were any possibility of ADS-B transmission overlap with a ground message.

NOTE: Random access for ADS-B transmissions offers simplicity and robustness at some expense of spectrum efficiency.

NOTE: Airborne UATs will not be critically dependent on precise timing to support ADS-B media access. However availability of accurate timing will allow airborne transceivers to perform a passive range validation of ADS-B reports as described in Section D.2.1.2.2.1.

D.1.1.2 End State Protocol

The description in D.1.1.1 above represents the proposed net access protocol in an end state configuration.

D.1.1.3 Relationship of Test Circumstance to End State

D.1.1.3.1 Access Protocol

The description in D.1.1.1 above represents the net access protocol implemented in the test configuration and is also consistent with that of the proposed operational system.

D.1.1.3.2 Backup Timing

Test units do not support the backup timing of the airborne UAT from receipt of ground broadcast messages. It is expected that “end state” units could however support this function in order to maintain transmitter timing in the event of GPS outage. The primary benefit of this backup timing information is that independent ADS-B range validation can continue to be supported.

D.1.2 Waveform

D.1.2.1 Channel Frequency(s) and Modulation Technique

The UAT transceiver operates on an experimental frequency assignment of 966 MHz.

Rationale - Use of a single common global channel is the simplest architecture for supporting ADS-B since seamless air-air operation is required. As a result, the channel should offer significant bandwidth to assure adequate capacity and performance. This band was selected due to the wide channelization (1 MHz) that currently exists there and the potential availability of certain channels that could be reserved on a global basis. However, the system is not frequency specific and could operate in any suitable spectrum.

Data shall be modulated onto the carrier using binary Continuous Phase Frequency Shift Keying. The modulation index, h, shall be 0.6; this implies that if the data rate is R_b, then the nominal frequency separation between “mark” (binary 1) and “space” (binary 0) is $\Delta f = h \bullet R_b$. A binary 1 is indicated by a shift up in frequency from the nominal carrier frequency of $\Delta f/2$ and a binary 0 by a shift of $-\Delta f/2$.

The signal shall be filtered to give a reasonably compact frequency spectrum. (The “mask” specifying the bandwidth occupied by the signal is TBD.) This filtering may be done either at the baseband waveform prior to modulation, or on the modulated signal, or both, as necessary.

Rationale - This modulation scheme permits relatively simple, inexpensive nonlinear transmitter and receiver implementations. It also offers a relatively high tolerance to self-interference.

D.1.2.2 Channel Rate and Bit Structure

The modulation rate is 1.041667 megabit/second. This rate, coupled with the modulation index of h = 0.6, would imply that Δf = 625 kHz, and that the deviation from the carrier frequency is ±312 kHz. (In practice, however, because the filtering for bandwidth limitation introduces some overshoot in the deviation, the maximum deviation is closer to ±450 kHz.)

D.1.2.3 Synchronization and Preamble Characteristics

D.1.2.3.1 Preamble Sequences

To allow for receiver stabilization and to minimize transient spectral components, the transmitter power shall ramp up and down at the start and end of each burst. The maximum time duration of these ramps shall be no more than 4 bit periods each. Ramp time is defined as the time between 90 per cent power output and -60 dB power output. During ramp up and down, the modulating data shall be all zeroes. Following ramp up, each data burst will include a 36 bit synchronization sequence. For the ADS-B messages (from aircraft) the sequence will be

111010101100110111011010010011100010

with the left-most bit transmitted first.

For ground broadcast messages, the polarity of the bits of the synchronization sequence is reversed, that is, the ones and zeroes are interchanged. This synchronization sequence is

000101010011001000100101101100011101

NOTE: Because of the close relationship between the two synchronization sequences, the same correlator can search for both simultaneously.

NOTE: These sequences were selected for their good autocorrelation properties.

D.1.2.3.2 Preamble Retrigger

Preamble retrigger allows the receiver to perform the sync detection process on multiple messages simultaneously in the event of message overlap—in particular when a stronger message follows a weaker one. Test units do not incorporate this function, but it is expected that end state units would support this to fully exploit the "capture effect" of the waveform in cases where a stronger ADS-B message overlapped a previous weaker one.

D.1.2.4 Message Structure and Coding

D.1.2.4.1 ADS-B Messages

Exactly one ADS-B message is transmitted per aircraft every second. Figure D.1-3 shows the format and components of the ADS-B message burst transmission from aircraft (or ground vehicles).

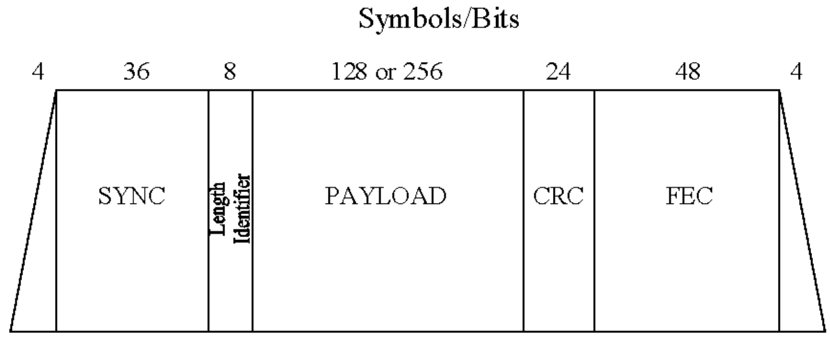


Figure D.1-3: ADS-B Message Format

D.1.2.4.1.1 Length Identifier Field

As indicated in Figure D.1-3, the "payload" part of the ADS-B burst can be either 128 or 256 bits long. When the payload length is 128 bits (the "basic ADS-B message" format), the length identifier field is coded as 0F hex. When the payload length is 256 bits (the "long ADS-B message" format), the length identifier field is coded as F0 hex.

D.1.2.4.1.2 Payload Field

The payload part of an ADS-B message carries actual ADS-B data: the information needed by the receiving ADS-B participant to assemble reports for the client application. The data elements for these reports are defined by the ADS-B MASPS.[D2] The UAT System Description Document details the data format of both the basic and long message payloads. Table D.1-1 below gives a message-to-report mapping for each ADS-B message type.

D.1.2.4.1.3 CRC Field

Following the payload is a 24-bit cyclic redundancy check (CRC) code. The particular code used is the CRC-24Q code, for which the generating polynomial is

$$GP(x) = x^{24} + x^{23} + x^{18} + x^{17} + x^{11} + x^{10} + x^{7} + x^{6} + x^{5} + x^{4} + x^{3} + x + 1$$

[D2] RTCA/DO-242, *Minimum Aviation System Performance Standards for Automatic Dependent Surveillance – Broadcast*

Table D.1-1: ADS-B Message Burst to Report Element Mapping

			State Vector (SV) Elements																		Mode Status (MS) Elements														On Cond'n (OC) Elements							
	Average per Aircraft Broadcast Rate (hz)	RF Burst/Msg Type \ Element Description	ICAO Addr.	Latitude	Longitude	Alt. (Geo)	NUCp	Geo. Pos. Valid	N. Velocity	E. Velocity	Vert. Rate (Geo)	NUC_R	Alt., (Baro)	Baro Alt. Rate	Airspeed	Gnd Spd, Gnd Trk	Turn Indicator	Time of Applicability	Report Mode		ICAO Address	Call Sign	Category	Surv. Support	Emrg/Priority Status	Appl. Class Code	TCP Latitude	TCP Longitude	TCP Altitude	Time to Go	Opn Mode Specific Dat	Flt Mode Specific Data	Time of Applicability		ICAO Address	TCP+1 Latitude	TCP+1 Longitude	TCP+1 Altitude	TCP+1 Time to Go		Spare or Other	Total Payload Bits
Evaluation Uni	0.6	Basic	25	24	24		4	1	11	11		4	12	9				*			N/A														N/A						3	128
	0.2	Type 0 Extended	25	24	24	13	4	1	11	11	8	4	12	9	12		2	*			N/A	43	5		3	12									N/A						33	256
	0.2	Type 1 Extended	25	24	24	13	4	1	11	11	8	4	12	9	12		2	*			N/A				3	12	20	20	12	12					N/A						17	256
Operational Syste		Basic**	25	24	24		4	1	11	11		4	12	9				*			N/A														N/A						3	128
	0.25	Type 0 Extended	25	24	24	13	4	1	11	11	8	4	12	9	12		2	*			N/A	43	5		3	12									N/A						33	256
	0.5	Type 1 Extended	25	24	24		4	1	11	11		4	12	9				*			N/A						20	20	12	12					N/A	20	20	12	12		3	256
	0.25	Type 2 Extended	25	24	24		4		11	11		4	12	9			2	*			N/A	<130 bits for future definition>													N/A						130	256

* Time of applicability is implicit and tied to the UTC second prior to transmission

** Full capability participant would not use the Basic Message

The CRC acts as a 24-bit parity code, generated from the 128-bit or 256-bit payload by a certain algorithm. With a 24-bit parity code, the probability of not detecting a corrupted payload is approximately 2^{-24}, or 5.96×10^{-8}.

D.1.2.4.1.4 FEC Field

After the CRC comes a 48-bit FEC (Forward Error Correcting code) field using a Reed-Solomon (RS) code. The purpose of this field is to permit the (payload + CRC) data to be transmitted reliably over the air; as an error-correcting code, the FEC permits "bad data bits" (data bits corrupted by noise or interference) to be corrected. This correction process has a certain (low) probability of generating an incorrectly "corrected" bit sequence. If this should occur, the CRC code will permit the detection of that incorrect data. The result of this dual error detection process (error detection and correction using the FEC field, followed by the detection of remaining errors using the CRC field) will be to ensure, with a very high level of confidence, that no bit error will go undetected.

The (payload + CRC + FEC) group of fields may be termed a "Reed-Solomon block" - a sequence of data bits (payload + CRC) together with the FEC Reed-Solomon code that protects those data bits against corruption.

NOTE: This will allow correction of any 3, 8 bit words in the Reed-Solomon block.

D.1.2.4.2 Ground Broadcast Message Format

Figure D.1-4 shows the format of the burst transmissions from a ground broadcast transmitter. It differs from the ADS-B burst from aircraft in the following ways:

- There is no "length identifier" field, because transmissions from ground stations are always the same length.
- The burst is organized into two Reed-Solomon blocks rather than one.
- The payloads and FEC fields in those blocks are longer than in the shorter ADS-B block. (With more payload bits to be protected, a longer Reed-Solomon forward error correcting code is required.)

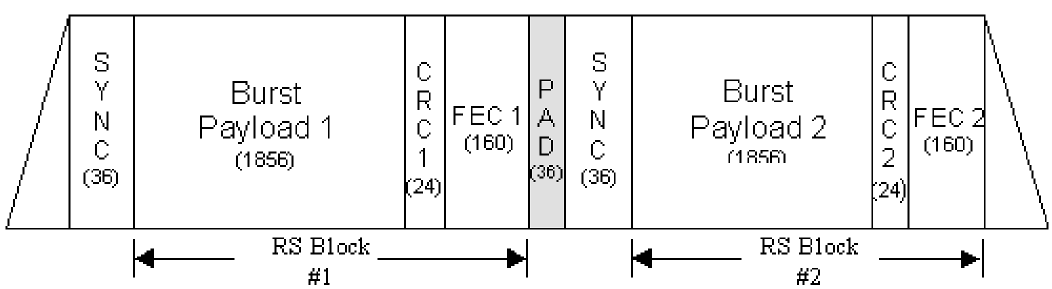


Figure D.1-4: Ground Message Format

The number of bits/symbols which make up each segment of the burst is shown in parenthesis. The segment labeled "pad" carries no information.

D.1.3 Messages and Reports

D.1.3.1 Message Types and Broadcast Rates

The message types and their contents are shown in Table D.1-1. The set of message types is shown for both the evaluation units and the proposed operational system. It is assumed that VFR users desiring anonymity could transmit the basic message in the majority of cases.

Evaluation units are configured to transmit the following message types in a 5 second epoch:

- basic burst: 3 times,
- type 0 extended length message: once, and
- type 1 extended length message: once (no TCP information will be present)

In the proposed operational system, it is expected that message transmissions would rotate through the set of 3 extended length message types in sequence through a 4 second epoch as shown. This assumes a full capability participant; others could make some use of the Basic Message.

D.1.3.2 Relationship Between Message Receptions and Output Reports

The relationship between message (or RF burst) receptions by the UAT receiver and ADS-B reports output by that receiver to an application is a simple mapping function. Every UAT message received acts as a stimulus to output reports whose elements are simply mapped from those contained in the burst. Table D.1-2 below lists the types of message stimuli and the corresponding response of the UAT receiver in terms of reports issued to an application (for the proposed operational system).

Table D.1-2: Message to Report Mapping

RF Message (or burst) Stimuli	UAT Receiver Response in Form of Reports Issued*
Basic	SV(1-3, 5-8, 10-12)
Type 0 Extended	SV(1-13, 15) & MS(1-3, 5, 6)
Type 1 Extended	SV(1-3, 5-8, 10-12) & MS(1, 7-10) & OC(1-5)
Type 2 Extended	SV(1-3, 5-8, 10-12) & [TBD]

*SV, MS, AND OC REPORT ELEMENTS DEFINED IN RTCA DO 242 ADS-B MASPS

The following points relate to the information in the table above:

- UAT ADS-B receive function includes Reed Solomon FEC decoding and 24 bit CRC integrity check
- Every burst is self-contained in that the receiver will yield corresponding report elements unambiguously and with required integrity directly. As a result no additional context validation or tracking filter is needed for report assembly or to provide extra protection against message corruption.
- All time critical SV elements are present in every burst (i.e., no fragmentation)

D.1.3.3 Relationship Between Report Update Rates and Supported Applications

ADS-B message transmission rate is fixed at once per second. This rate is designed to support all applications identified in RTCA DO-242.

D.1.4 Spectrum Issues

D.1.4.1 Channel Availability

<input from FAA/ASR>

D.1.4.2 EMC Effects of UAT on Other Systems

UAT was designed for operation on a clear channel. Influence to off channel systems can only be assessed once an operational frequency is identified. Figure D.1-5 shows the theoretical UAT spectrum when implemented with a raised cosine Nyquist filter for alpha equal to 0.5. The actual spectrum mask is TBD.

Since the waveform has a constant envelope, a high degree of linearity in the transmitter amplifier is not necessary to preserve the spectral containment.

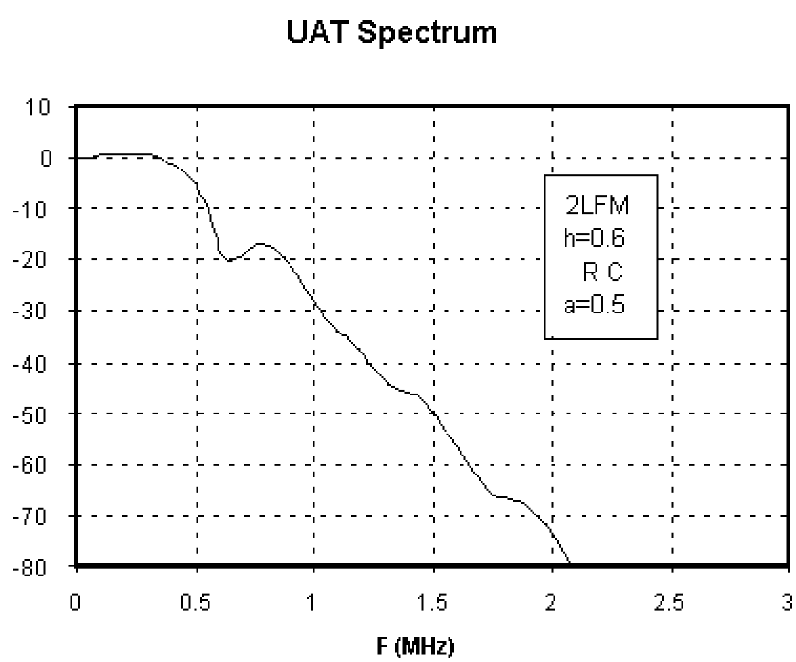


Figure D.1-5: UAT Spectrum (Theoretical)

D.1.4.3 EMC Effects of Other Systems on UAT

UAT is designed for operation on a clear channel. Influence from off channel systems can only be assessed once an operational frequency is identified.

D.1.5 Link Budget Parameters

D.1.5.1 Power

The test units operate at 50W at the transceiver terminals. The expected range of power levels for full scale operational systems is +40 to +48 dBm (at the antenna terminals).

D.1.5.2 Receiver Sensitivity

The test units operate at a nominal sensitivity of approximately -97 dBm at the receiver terminals. The expected minimum required sensitivity level for full scale operational systems is at least -92 dBm for all units when measured at the antenna terminals. The condition for this measurement is a 90% message success rate.

D.1.6 Role of the Ground Station Network

The ground subsystem will operate as an ADS-B sensor identically to that of airborne units. The ground subsystem will also be capable of transmitting on one or more of the 32 ground broadcast burst time slots for FIS-B uplink. TIS-B uplink from ground station will utilize the ADS-B message format and ADS-B segment as described in Section D.6.1. The ground station antenna is a 6-8 dBi omni DME-style. Figure D.1-6 gives an overview of the ground station.

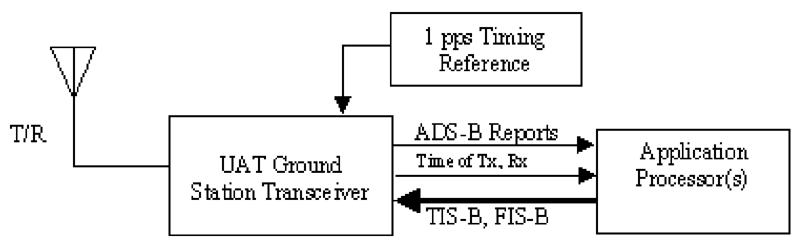


Figure D.1-6: Evaluation Unit Ground Station Block Diagram

A single ground station antenna/transceiver are capable of supporting the following functions:

- ADS-B sensor
- Provides time-of-arrival measurement of ADS-B transmission for independent range to target measurement based on a single sensor. Networked ground stations with overlapping coverage allows surveillance based on the "multilateration" technique wherein a 2-D position is derived completely independent of the ADS-B reported position.
- TIS-B uplink
- FIS-B uplink
- Provides timing beacon to airborne users that can serve as backup timing (see Section D.1.1.3.2).

D.2 System Overview

D.2.1 CNS Architecture

D.2.1.1 Intended Surveillance Role

The UAT message structure, net access scheme, and signal structure were designed to support all applications listed in DO-242. A range of UAT implementations are expected that would meet requirements of users in categories A0 through A3 as described in Section D.5.3.

D.2.1.2 Quality of Service

D.2.1.2.1 Availability/Continuity of Service

The following describes some possible failure scenarios, the associated response of UAT avionics, and the resulting impact on air-air surveillance.

Table D.2-1: Failure Scenarios and their Impact

Failure	Response	Operational Impact on A-A Surveillance
GPS Outage	⇒ Avionics continue ADS-B reporting if alternate nav source is available. ⇒ Media access timing slaved to ground station uplink if available, ELSE coast timing ⇒ Alternate nav source could be UAT gnd stations if in overlapping coverage	⇒ Lower performance NUC value with alternate nav source ⇒ ADS-B passive range validation not available in timing coast (i.e., no gnd station in range).
Ground station outage	No special action required	No impact on air-air ADS-B
Inflight cold reset/restart	⇒ Instant net entry ⇒ Instant decoding and operational use of received bursts	None after restart for short range applications

D.2.1.2.2 Integrity

D.2.1.2.2.1 Report Validation

ADS-B burst transmissions always start at one of 4000 Message Start Opportunities (MSO) in every 1 second UAT frame. Every frame an MSO is selected on a pseudorandom basis such that no two aircraft will repeatedly select the same MSO. The Type 0 Extended ADS-B burst contains a 12 bit field that encodes the MSO in which that transmission began. A receiver can—by knowing the MSO of the transmission and the time of receipt—calculate the propagation time of the message and hence range to target. This time can be used by airborne receiving systems or applications to perform a validation check of the range to the target as encoded in the ADS-B positional information. Ground stations can perform a similar function to validate range to a single station, or if at least three stations are in range of a given target, actual validation of the reported position can be performed using differential-time-of-arrival techniques. It is estimated that a receiver can reasonably measure time of arrival with accuracy better than

0.5 of a symbol period (500 ns). Evaluation units will support collection of data that can be used to determine this accuracy.

D.2.1.2.2.2 Probability of Undetected Message Error

UAT employs a Reed Solomon (RS) FEC with 48 bits of FEC redundancy on ADS-B messages. This level of RS FEC provides approximately $1.6x10^{-3}$ worst case probability of undetected error for any ADS-B burst. Additionally, the 24 bit CRC reduces this further by another 2^{-24} or $5.96x10^{-8}$. Therefore the worst case overall undetected error probability for an ADS-B message is $3.7x10^{-11}$.

D.2.2 Transition Approach

Aircraft under TCAS mandate will carry UAT alongside TCAS. UAT will augment TCAS and the display of traffic to enable enhanced visual procedures not supported by TCAS alone. Early equipage will coincide with specific fleet operations requirements. Later, equipage will be affected by evolving capacity and safety enhancements such as paired approach, station keeping and surface surveillance. Finally, UAT systems will form the basis for future collision avoidance, utilizing the passive ranging capability in conjunction with ADS-B.

Non-TCAS aircraft will carry UAT alongside the existing transponder through the transition period. The first to equip will receive traffic in the cockpit (TIS-B) as well as graphical weather. Later UAT will serve an increasing role in navigation and surveillance. Figure D.2-1 shows the transition timeline.

D.3 Information Exchange Functionality

D.3.1 Broadcast Message Generation

D.3.1.1 Information Source Interface and Information Compression

Under normal conditions it is expected that the UAT would interface with a GPS sensor and baro altitude source for any minimal installation. The GPS sensor would provide the position and velocity information as well as timing for ADS-B transmissions. No compression is used in encoding ADS-B information. Timing requirements are limited to a 1 pulse per second signal.

D.3.1.2 Message Assembly, State Vector Extrapolation, and Broadcast

In evaluation units, position information is extrapolated to provide a 2 hz update rate to the transmitter. This results in a time of applicability no greater than 500 ms from time of reception. Complete state vectors are contained in every transmission. Transmission rate is 1 hz average.

In end state units, position data in ADS-B messages will have a time of applicability based on the UTC second just prior to the transmission.

D.3.1.3 User Adaption Features

Anonymity: Upon initialization of UAT, a user who wishes not to broadcast their ICAO address can set the “anonymity bit.” This replaces the 24 bit assigned address with one generated pseudorandomly at time of initialization. The anonymity bit is provided in the test units, however all CAA/Ohio Valley tests are expected to use discrete addresses.

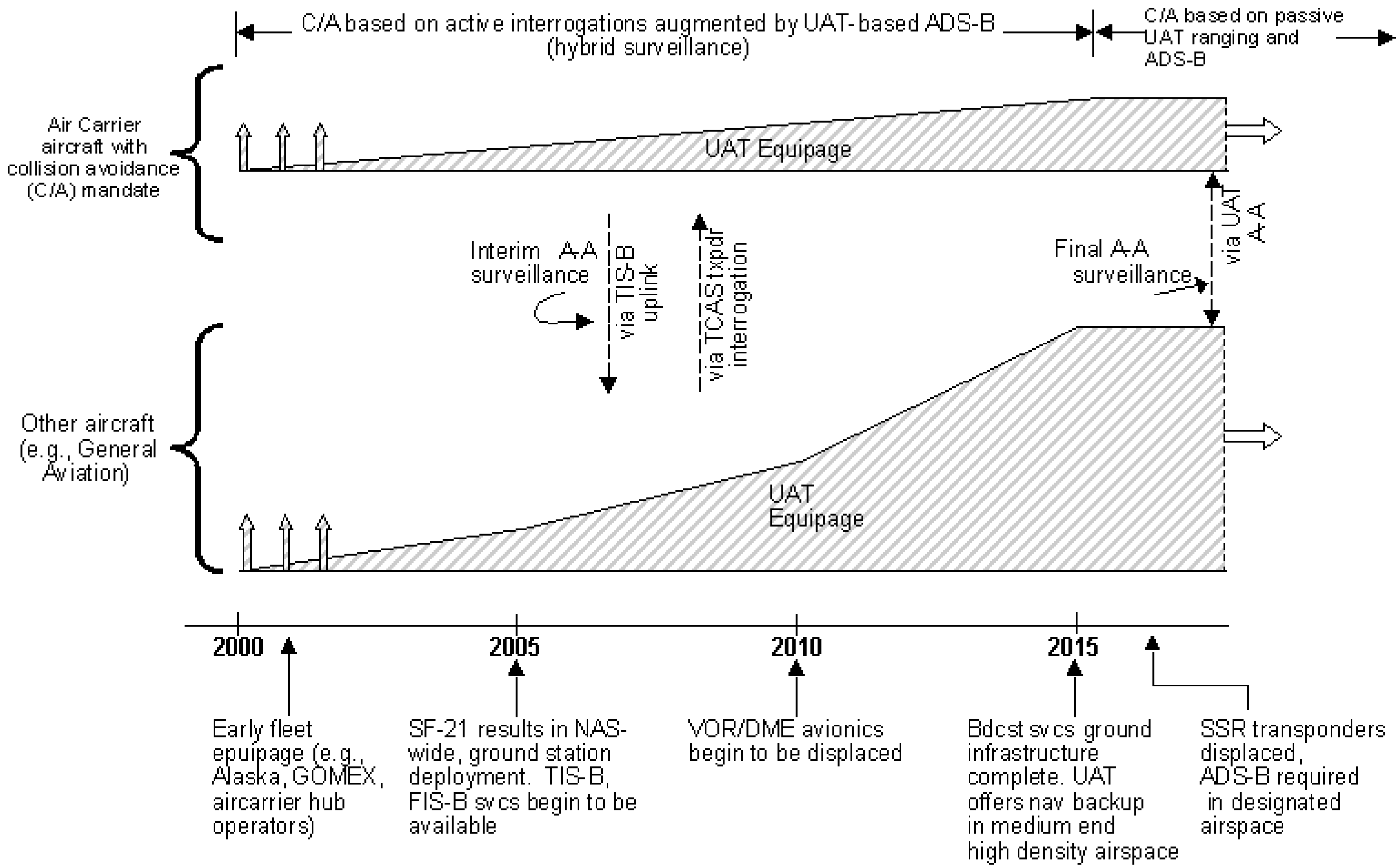


Figure D.2-1: UAT Transition and Role in CNS Architecture

D.3.2 Message Reception and Output Reports

Refer to Table D.1-2.

D.3.3 Reports and Supported Applications

D.3.3.1 Output Format wrt MASPS Format

Since all dynamic state vector elements are contained in every UAT message, UAT message payload is forwarded to applications without the need for decompression or message assembly.

D.3.3.2 Application Interface

Since all dynamic state vector elements are contained in every UAT message, UAT message payload is forwarded to applications without the need for decompression or message assembly.

D.4 Message Reception and Co-Channel Interference

D.4.1 Interference Sources

D.4.1.1 TDMA Slot Overlap (Ground Uplink Transmissions)

The segment of the UAT frame used for ground uplink operates as a slotted TDMA access. Proximate ground stations would be assigned different time slots in order that cochannel interference is controlled.

D.4.1.2 Random Access Interference (ADS-B Transmissions)

As described in Section D.1.1.1, ADS-B transmissions occur at a pseudorandomly determined time based on one of 4000 Message Start Opportunities (MSO). Since time spacing between MSOs is less than the duration of an ADS-B message (plus guard time), the system behaves essentially as an unslotted random access. Since UAT is based on a clear channel concept, the system is limited only by system self-interference.

D.4.1.3 Ownship Supression Effects on Link Availability

No ownship supression circuitry is used either to or from the UAT system on the test aircraft. The need for this in the end state may depend on the other equipment on the aircraft and the end state frequency assigned for UAT.

D.4.2 Decoder Response

D.4.2.1 Synch Detection and False Synch Lockout Time

UAT test units perform a sync lockout upon detection of the sync preamble. This is to avoid detection of the occurrence of the sync sequence in the data. UAT end state units are expected to be able to operate with a preamble retrigger capability in parallel with processing of the previous overlapped message.

D.5 Subsystem Block Diagrams

D.5.1 Evaluation Unit Airborne Subsystem

Figure D.5-1 shows a high level block diagram of the evaluation units.

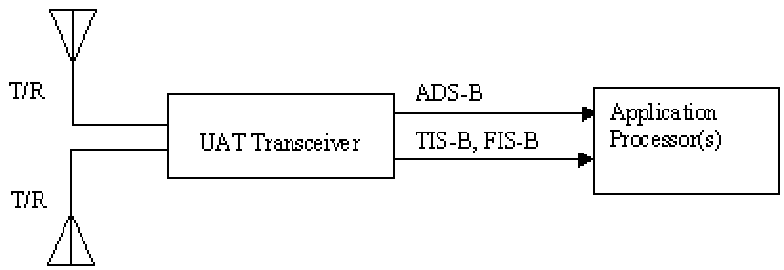


Figure D.5-1: Block Diagram of Evaluation Units

Top/bottom antenna switching is performed by the transceiver independently for transmit and receive as follows:

- Transmit: T T B B T T B B (Antenna selection for transmit alternates every 2 seconds)
- Receive: T B T B T B T B (Antenna selection for receive alternates every second)

Link parameters for the 1999 test equipment and for the planned operational system are compared in Table D.5-1.

D.5.1.1 Message Generation and Input Interface

See Section D.3.1.

D.5.1.2 Message Exchange Function (Link Budget and Assumptions)

D.5.1.2.1 Tx/Rx Antennas

Evaluation units on CAA aircraft are implemented as a single transceiver that switches automatically between top and bottom mounted antenna in alternate 1 second intervals for both transmit and receive. Antennas are quarter wave blade style and are cut to 966 MHz.

D.5.1.2.2 Receiver/Decoder

MTL response curve to be provided by APL characterization. Evaluation units will be able to perform overlap decoding in the case of a weaker message that overlaps a previous stronger message. A preamble retrigger function not included in the evaluation units will be required to support overlap processing when a stronger signal follows a weaker one.

D.5.1.3 Report Assembly Function and Output Interface

See Sections D.1.3.1 and D.1.3.2.

Table D.5-1: Basic UAT Parameters

	UAT	
	Operational System	**1999 Tests**
Frequency Band	not assigned	966 MHz
Bit Rate	1 Mb/s	same
Modulation	Binary GFSK + 312 KHz	same
Preamble	first 36 bits	same
Message Length	246 bits, short 372 bits, long	same
Parity	48 bits FEC and 24 bits CRC	same
Address	25 bits	same
Longitude	24 bits	same
PVT Segmentation?	together	same
Transmitter power (at antenna)	46-48 dBm, high-end 40-42 dBm, low-end	44 dBm +/-3 dB
Receiver MTL (at antenna)	<= -92 dBm	-94 to -93 dBm
Polarization	vertical	same
Transmission Rate, PVT	1/sec.	same
Multiple Access Technique	slots to separate ground/air, aircraft use random short messages	same
Channels	one channel	same
Guard Channels?	TBD	current assignments

D.5.1.4 Relationship with Other Ownship Subsystems

UAT is new equipment that is independent of any existing equipment on the aircraft other than for ownship sensor inputs. No coordination with other equipment is used (e.g., for mutual supression).

D.5.2 Evaluation Unit Ground Subsystem

The ground subsystem used in the evaluation, and described in Section D.1.6, is consistent with that proposed for the operational system.

D.5.3 Proposed Equipage Classes

Several airborne configurations could be possible depending on the range and system availability required for the user. In addition to the evaluation unit configuration shown in Section D.5.1, the configurations shown below are also possible:

- Basic: Consist of a single transceiver without antenna switching diversity. This configuration may be sufficient for A0 users.

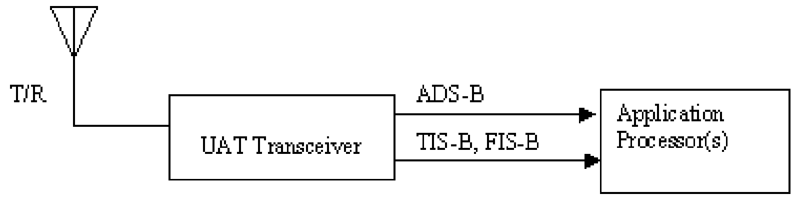


Figure D.5-2: Basic Installation for Low End Applications

- High performance (w/ RF monitoring and redundancy): dual transceivers each hard wired to top and bottom antennas respectively. Could include higher transmitter power (for e.g., >100 nmi range) if needed for applications beyond MASPS. This configuration may be desirable for advanced applications associated with the A3 user class.

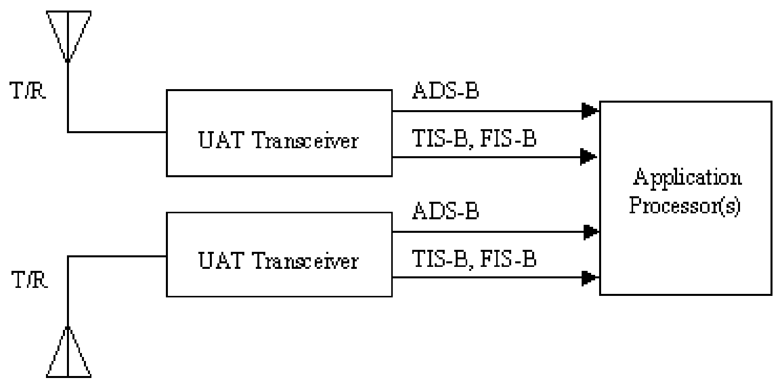


Figure D.5-3: High Performance Installation for "Free Flight" Applications

D.6 Other Situational Awareness Services

D.6.1 TIS-B Description

TIS-B will be supported in the UAT with a shared bandwidth concept with the ADS-B channel resources. This is logical since the concept for TIS-B is that TIS-B reports are to be made only for non-ADS-B aircraft. Therefore as more aircraft become equipped with ADS-B the need for channel resources for TIS-B decline.

TIS-B uplink burst transmissions will consist of concatenated target reports in the link standard ADS-B message format. The packaging of the TIS-B uplink burst transmission is shown in Figure D.6-1. This packaging has the advantage of offering consistent TIS-B/ADS-B target processing by the avionics. It also offers some robustness to collision with an ADS-B message transmission from aircraft. Since each

TIS-B target report packed within the TIS-B uplink burst is self contained (in that each can be independently detected by a receiver), such an overlap will corrupt only the overlapped portion of the full TIS-B uplink burst.

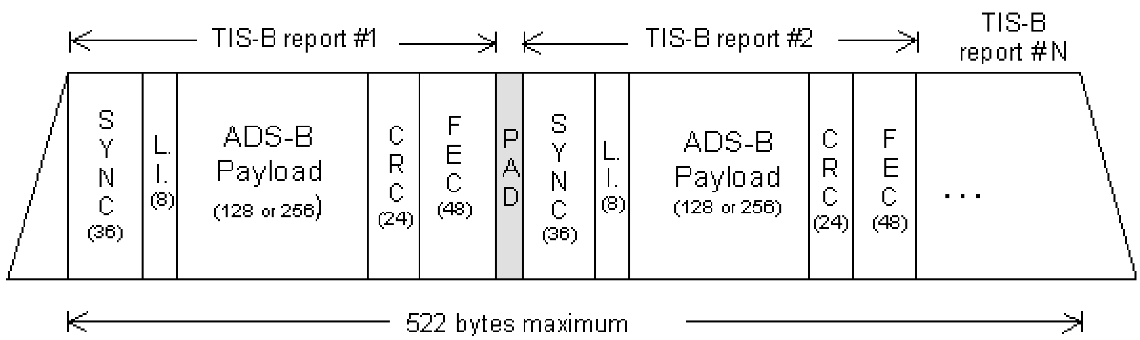


Figure D.6-1: TIS-B Uplink Burst Format

From Figure D.1-1 it can be seen that the ground broadcast segment consists of 32, 5.5 ms time slots that are time segregated from ADS-B message transmissions. These slots are referred to as protected slots. The approach for TIS-B uplink effectively adds another 32 time slots directly following these 32 in the ground broadcast segment. These additional 32 time slots are also each of 5.5 ms duration and are used only for TIS-B uplink burst transmissions. Procedures for ADS-B message transmission by aircraft is unaffected by this approach to TIS-B uplink; collisions are possible—and are accounted for—just as they are amongst ADS-B messages. Therefore this second set of 32 slots are referred to as unprotected slots. Note that for critical TIS-B applications (e.g. approach monitoring) protected slots could be used if desired.

Figure D.6-2 shows the overall media access concept including TIS-B.

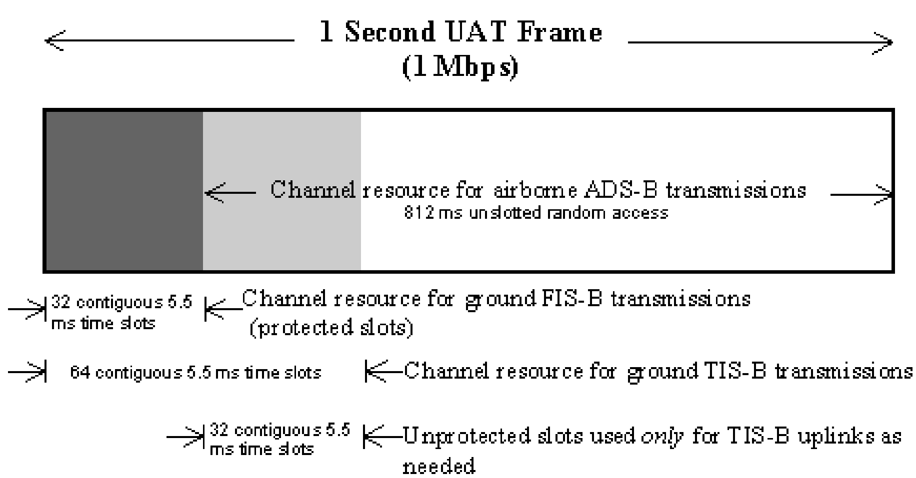


Figure D.6-2: Overall Media Access Plan with TIS-B

D.6.2 FIS-B Description

FIS-B is supported with protected time slots in the ground broadcast segment of the UAT frame. The total bandwidth available to each ground station can be estimated using some simplifying assumptions:

- All ground stations operate in a regular cellular pattern with intersite spacing of approximately 100 nmi.
- The UAT waveform's tolerance to cochannel interference will dictate the cellular reuse pattern that can be achieved as follows if free space path loss is assumed for the desired and undesired signals:
  - 4 cell pattern ~1:2.5 desired to undesired (D/U) distance ratio (8 dB)
  - 7 cell pattern ~1:3.6 D/U distance ratio (11 dB)
  - 12 cell pattern ~1:5 D/U distance ratio (14 dB)
  - 19 cell pattern ~1:6.5 D/U distance ratio (16 dB)
- Assume the UAT waveform gives at least 90% message success rate at 6 dB D/U based on bench measurement.
- If 5 dB margin for fading is assumed, this allows operation with 7 cell pattern.

Therefore if bandwidth is distributed evenly between the sites, each site could operate with 4 time slots at ~3.7 kbps payload per slot for a total bit rate of about 15 kbps per site.

D.7 Growth Potential and Other Features

D.7.1 Capacity for Extra ADS-B Payloads and Applications

From Table D.1-1 it can be seen that there are two message types defined that in addition to conveying the complete state vector, also have about 90 additional bits of payload that is undefined and could be used for reporting data not included in DO-242. Examples of such data would be additional TCPs or weather data from pilot entered data or on-board automated sensors.

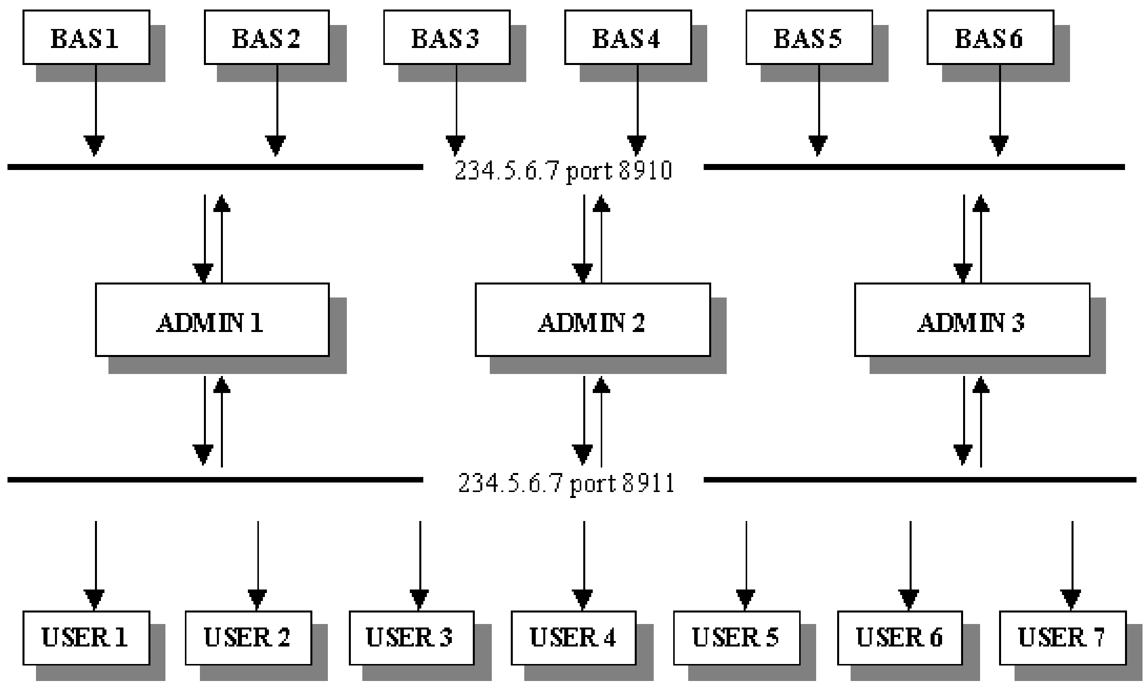
D.7.2 Backup Navigation From Ground Stations

Evaluation units will be capable of transmitting and recording the information necessary to assess the backup navigation performance as supported by the UAT waveform. This capability is related to that discussed in Section D.2.1.2.2.1 used for range validation of ADS-B reports.

Attachment D1

Schematic Ground Network Architecture -
Multicast of Position Reports Over Network

Distribution of ADS-B reports with a point-to-point type of network will result in high load on the network and consequently high costs for leasing required bandwidth in dedicated networks. This paper is discussing alternative network architecture and a method of message distribution that could provide a high level of redundancy at low cost. The proposed method is the implementation of a network based on the ”multicast” -principle that will result in low load and consequently low capacity requirements. Multicast means that the servers are automatically creating a tree-structure. This technology is implemented and used on many standard off-the-selves servers such as Windows NT and Winsock 2.0. The following figure explains the principle architecture for position reports. (see also Appendix D Attachment 2, “Network Load per Client”).



In the simplest system configuration two (2) multicast addresses are used which in the above example are named 234.5.6.7 port 8910 (primary) and 234.5.6.7 port 8911 (secondary). In the above example there are six (6) base stations which are programmed with **GPCmultiTX or GPClog** that are sending position reports on the international common primary address (234.5.6.7 port 8910). To support the **GPCmultiTX** programme the GNSS-Transponder base stations type R2/T2 (from version 11.5; 16 March 1996) include the identity of the base station by setting the parameter NETHEAD EQU 1. Since the base stations should be organised to provide overlapping coverage multiple base stations will receive the same message. Therefore, there will normally be more than one copy of each message in the network on the so-called primary address.

In order to minimise the load on the network and to manage the network one or more computers are used which in this example are called **admin**. Only one of these computers are active and the other(s) are on stand-by in case of failing main or master computer. This will secure the necessary redundancy of the network system. The software package for the network management computers **- GPC admin -** is identical and can operate on a selected number of computers located at different geographical locations in the network. The network management programmes are communicating with each other over the common "multicast address" in order to continuously update the database (tracker) and will establish the priorities in case of failure of the master computer. The switch over time to one of the stand-by computers can be made within maximum 10 seconds.

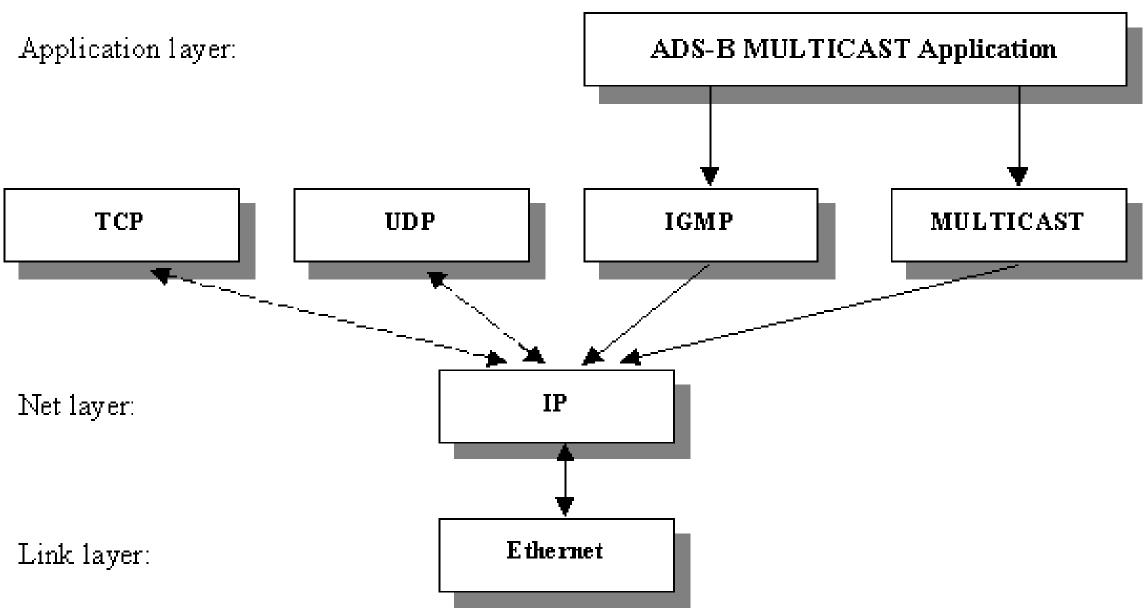
The main task for **GPC admin** is to assemble messages (position reports, etc.) and copies of those from the primary address and to transfer ONE (1) copy of each message to the secondary address, and to update the data base which is monitoring the traffic situation in the network.

The blocks manned USER is a presentation programme (software package) which is using the programme **GPC multiRX** that is establishing the "multicast" connection and thereafter reception of position reports. This programme should normally be integrated into the application software.

For end-to-end communication, for instance text messages, **GPC multiRX** and **GPC multiTX** are communicating directly or via **GPCadmin** through a point-to-point connection based on TCP/IP.

For global implementation it is recommended to use several multicast addresses with different update rates adopted to traffic conditions within the different geographical areas. A detailed description of the application protocols can be found in Appendix B.

The figure below is illustrating the principles of multicast.



Multicast is using **INTERNET Class D Addresses** in which the four most significant bits in the IP address is 1110 corresponding to IP addresses from 224.0.0.0 to 239.255.255.255. The initiation of multicast is done by using an **IGMP** (Internet Group Management Protocol) message (specified in RFC 1112 [Deering 1989]). This message is used to notify the servers of a multicast message and is called ”joining the multicast group”. The message consist of:

0 3	4 7	8 15	16 23	24 31
IGMP version	IGMP type 1-2	(unused)	16-bit checksum	
32- bit group address (class D IP address)				

An **IGMP-message** is transmitted as part of an **IP** message (specified in RFC 791 [Postel 1981a]). **IGMP** is always transmitted to the address 224.0.0.1 which is called the ”all-hosts group address”. After the initial **IGMP** the continued transmission or multicast of position reports is made by using the following **IP** message.

0 15			16 31	
4-bit version	header length	8-bit type of service (TOS)	16-bit total length (in bytes)	
16-bit identification			3-bit flag	13-bit fragment offset
8-bit time to live (TTL)		8-bit protocol	16-bit header checksum	
32-bit source IP address				
32-bit destination IP address				
Data				
Data				
……….				
Data				

Where:
TTL (Time To Live) is describing how many levels of servers that should forward the multicast message. By increasing the TTL the number of levels of "branches" it can be on the "server tree".

Basic Position Report Format from a Base Station

The out format from a base station is a string of ASCII characters. The string starts with '$PRGPS,’ followed by the message and finally *## (## = checksum). The checksum is obtained by XOR of all bytes between '$' and '*'. (Note! '$' and '*' are not included). The format and the checksum are in accordance with the NMEA-0183 standard. The string is terminated by CR+LF. The data rate is normally 19200 (9600 is used only for test and trials). The checksum including '*' can be omitted but is to be recommended. Should compatibility with NMEA-0183 not be required, also 'PRGPS,' can be omitted. The string will then start with merely a '$' character. In order to shorten the message length between the base device and the control center, 'PRGPS,’ is not normally used from the base device.

Position: $ITTTTTTTTXXXXXXXYYYYYYYSSSDDDZZZZZNTTS*##+CR+LF

where: I = type (1*ASCII HEX) 1= own GPS position, 2= incoming position
T = 8 characters identification e.g. SE-GNI_. (8* ASCII)
X = latitude in 1/1000 min. (7*ASCII HEX)
Y = longitude in 1/1000 min. (7*ASCII HEX)
S = speed in knots (3*ASCII HEX)
D = heading/direction in 1/10 degrees (3*ASCII)
Z = altitude in ft (5*ASCII HEX) FFFFF = land/see
N = navigation mode (1*ASCII HEX) 3 = 3-D nav. etc.
T = time for the position in seconds UTC (2*ASCII HEX)
S = climbing/descending, 1=up, F=down (1*ASCII HEX)

With 19200 bps this format is able to update about 42 active mobiles/second.

Networking of Base Stations

Base stations can suitably be linked up by connection to a network. The transmission within the network can, of course, for efficiency reasons be carried out by other methods than by ASCII strings. This, however, is a separate subproject, which does not concern the mobile GPS transponder. For networking during test and trials nine (9) ASCII characters has been added in the beginning of all messages from base stations. The purpose is to identify from **which base station** the majority of messages is coming during the last minute and **how many base station** received the same message.

CNNNNNNNN$ITTTTTTTT………*##+CR+LF

where: C = number of base station received the message (1*ASCII hex 1-F)
N = 8 characters id of main base station (8*ASCII).
$ = beginning of standard message from a base station.

Checksum is calculated between $ and * (the preceding data is not included).

Integrity

Many user groups are interested to have position information and movements of e.g. it own fleet secured from unauthorised use for instance for commercial or security reasons.

This is not a network issue. The required confidentiality can be provided by using encryption algorithms that is a part of the STDMA concept, and is already used in operational trials.

Attachment D2

Multicasting: A White Paper

Introduction

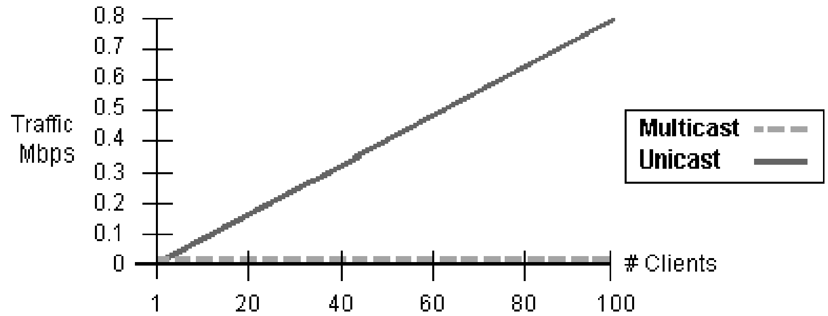
As personal computers have increased in power, that power has turned to running multimedia applications on the desktop. Now, multimedia applications are being designed for use on the network. Applications such as audio and video conferencing, and the transmission of live or recorded events using audio and video are only two of the many applications that blend multimedia and the network.

Today's networks are designed to reliably transmit data such as files from point to point. Multimedia places further demands on the network. First, data such as audio cannot tolerate delays in delivery. A network whose basic task is to move files from one place to another can transmit data packets at an uneven rate. If portions of a file arrive slowly or out of order, that is not a problem. Multimedia requires that data packets arrive at the client on time and in the proper order. Real-time protocols and quality of service guarantees on the network address this issue. Second, multimedia requires transmitting large amounts of data over the network and thus uses more of the network's bandwidth than basic network operations such as file transfer. Multicasting, the subject of this paper, addresses this issue.

Unicast, Broadcast, and Multicast

The bulk of the traffic on today's networks is unicast: A separate copy of the data is sent from the source to each client that requests it. Networks also support broadcasting. When data is broadcast, a single copy of the data is sent to all clients on the network. When the same data needs to be sent to only a portion of the clients on the network, both of these methods waste network bandwidth. Unicast wastes bandwidth by sending multiple copies of the data. Broadcast wastes bandwidth by sending the data to the whole network whether or not the data is wanted. Broadcasting can also slow the performance of client machines needlessly. Each client must process the broadcast data whether the broadcast is of interest or not.

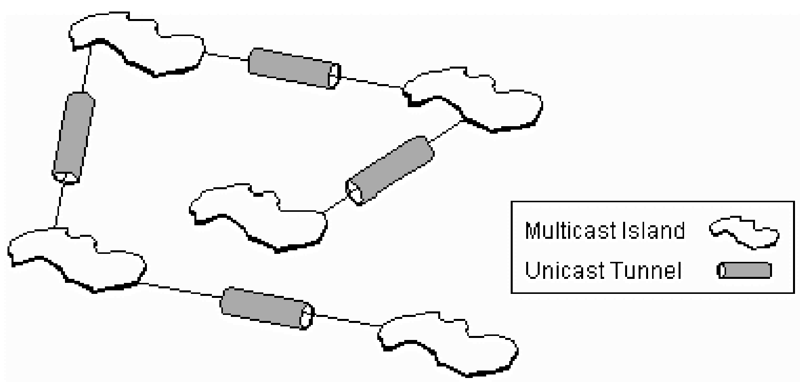
Multicasting takes the strengths of both of these approaches and avoids their weaknesses. Multicasting sends a single copy of the data to those clients who request it. Multiple copies of data are not sent across the network, nor is data sent to clients who do not want it. Multicasting allows the deployment of multimedia applications on the network while minimizing their demand for bandwidth. The following graph compares the network load per client when unicasting an 8 Kbps PCM audio stream and multicasting the stream and shows how a multicast saves bandwidth.



Network Load per Client

The MBone, LAN, and WAN

Today, the most widely known and used multicast enabled network is the Internet Multicast Backbone, the MBone. The MBone is a virtual network consisting of those portions of the Internet, sometimes called multicast islands, in which multicasting has been enabled. Multicasts that must travel across areas of the Internet that are not yet multicast enabled are sent as unicasts until they reach the next multicast enabled island. This process is referred to as tunneling.



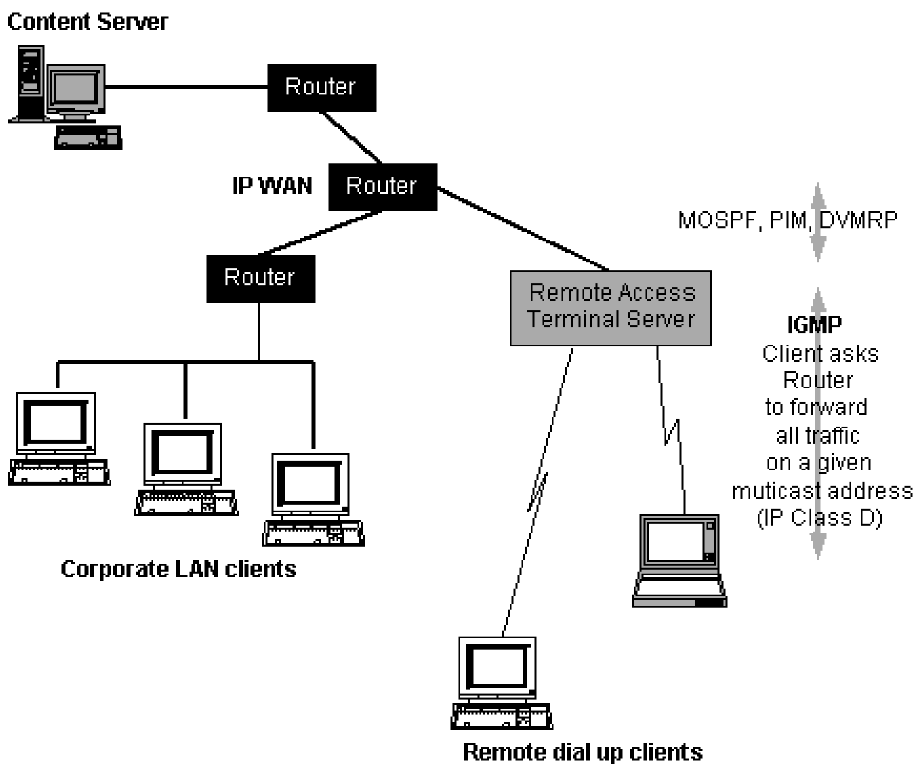
Multicast Islands and Tunnels

The MBone has been in place since 1992 and has grown to more than 2000 subnets. It has been used to multicast live audio and video showing Internet Engineering Task Force conferences, NASA astronauts working in space, and the Rolling Stones in concert. The MBone has successfully demonstrated the practicality and utility of using multicasting to send multimedia across the network.

The hardware for multicasting, chiefly multicast enabled routers and their software, has reached a point where corporations can take advantage of multicasting on their own LANs and WANs. The technology is of benefit in any scenario where several (or hundreds or thousands) of individuals need the same information. Because such information can be multicast live, multicasting is the ideal method to communicate up-to-date information to a wide audience. For example, sales trends for the week could be presented to all regional sales managers via multicast. Events such as a product introduction or important press conference could also be multicast. Multicasts can also support bi-directional communication allowing, for example, individuals in widely dispersed locations to set up a live conference that includes audio, video, and a white board.

How IP Multicasting Works

Multicasting follows a push model of communications. That is, like a radio or television broadcast, those who want to receive a multicast tune their sets to the station they want to receive. In the case of multicasting, the user is simply instructing the computer's network card to listen to a particular IP address for the multicast. The computer originating the multicast does not need to know who has decided to receive it.



Network Multicasting

Multicasting requires the following mechanisms:

- Clients must have a way to learn when a multicast of interest is available.
- Clients must have a way to signal that they want to receive the multicast.
- The network must have a way to efficiently route data to those clients who want to receive it.

<u>Announcing Multicasts</u>

Multicasts are announced in advance so that clients know when a multicast is available. On the MBone, multicasts are typically announced using the Session Description Protocol (SDP). This protocol supplies clients with all the information they need to receive a multicast including its name and description, the times it is active, the type of media (audio, video, text and so on) that it uses, and the IP addresses, ports, and protocol it uses. The announcement information is multicast to a well-known IP address and port where clients running the session directory tool receive this information.

In addition to SDP, there are other ways that multicasts can be announced. For example, on the corporate intranet, multicasts can be advertised using web pages. Controls embedded in the web page can then receive the multicast data.

Joining Groups

To signal that they want to receive a multicast, clients join the group to whom the multicast is directed. The Internet Group Management Protocol (IGMP) handles this task.

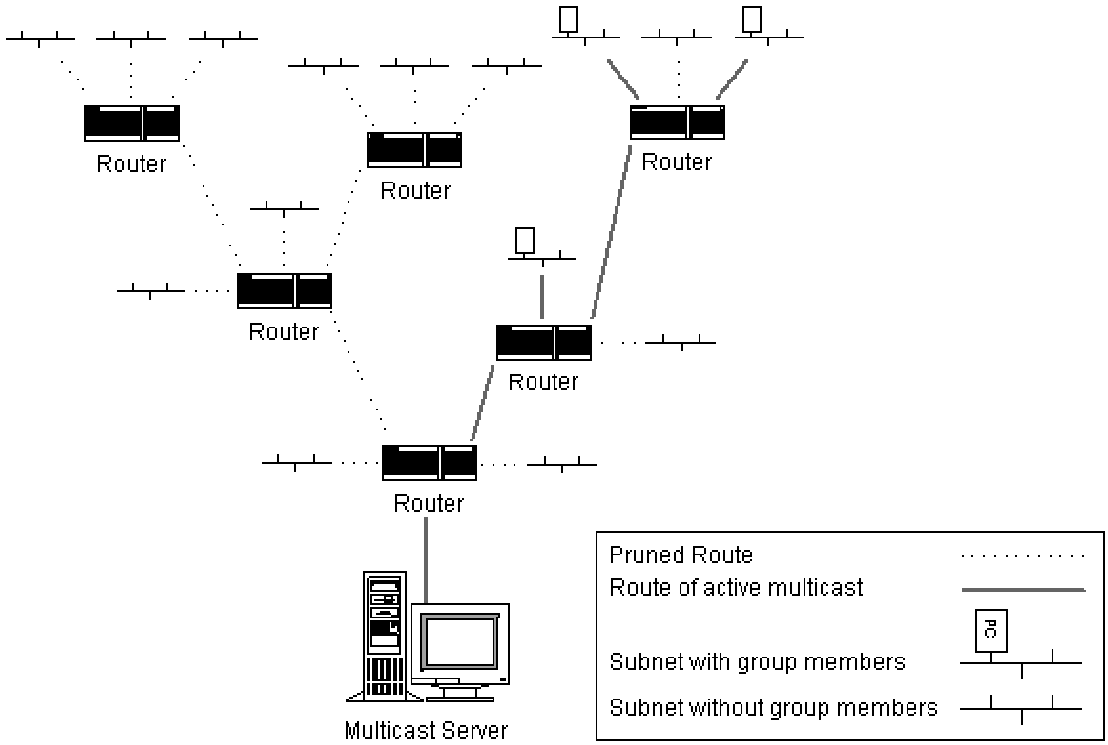
Multicast groups provide several advantages. Groups are dynamic: clients can join or leave at any time. No elaborate scheme is required to create or disband a group. When a group has no members, it ceases to exist on the network. Groups also scale upward easily because as more clients join a multicast, it becomes more likely that the multicast is already being routed close to them.

When a client joins a group, it initiates two processes: First, an IGMP message is sent to the client's local router to inform the router that the client wants to receive data sent to the group. Second, the client sets its IP process and network card to receive the multicast on the group's address and port. Multicast addresses are Class D IP addresses ranging from 224.0.0.0 to 239.255.255.255. Class D IP addresses map automatically to IEEE-802 Ethernet multicast addresses, which simplifies the implementation of IP multicasting on Ethernet. When a client leaves a group and is the only one receiving the multicast on that particular subnetwork, the router stops sending data to the client's subnetwork, thereby freeing bandwidth on that portion of the network.

Multicast Routing

The bulk of the work that needs to be done to enable multicasting is performed by the network's routers and the protocols they run. Two years ago major router manufacturers began adding multicasting capability to their routers. Multicasting can be enabled on such routers by simply updating their software and adding memory.

There are several multicast routing protocols in use today: Distance Vector Multicast Routing Protocol (DVMRP), Multicast Open Shortest Path First Protocol (MOSPF), and Protocol-Independent Multicast (PIM). The task of these protocols is to create efficient multicast delivery paths through the network. Multicast routing protocols use varying algorithms to achieve efficiency.



Routed Multicast Data Path

An efficient delivery path implies that multicast data travels only to those clients who want to receive it and takes the shortest path to those clients. If data travels elsewhere through the network, bandwidth goes to waste needlessly. You can visualize the network as a tree structure. The source of the multicast sends data through the branches of the tree. The routers are responsible for sending data down the correct branches to other routers and to the subnetworks where members of a group are waiting for data. Routers prune off branches where no one wants data and graft branches back to the tree when a client in a new subnetwork joins the group. Routers can also stop data from traveling to their own subnetworks when it is not wanted.

Summary

A new generation of multimedia applications that provide enhanced communication through the use of audio and video are ready to move onto the network. Multicasting provides an efficient way to enable these applications on the network:

- Multicasting can dramatically reduce the network bandwidth multimedia applications require.
- Servers do not require hardware upgrades in order to take advantage of multicasting.
- Clients do not require hardware upgrades in order to take advantage of multicasting.
- Because routers of recent vintage already support multicasting, enabling multicasting on the network is practical and cost-effective.

System Description for VDL Mode 4

Proposed for Link Evaluation of the Safe Flight 21 Applications

7 November 1999

Material prepared for the FAA Safe Flight 21 Technical/Certification Group,

Link Evaluation Task, RTCA Free Flight Select Committee

Abstract

This document provides a brief description of the VDL Mode 4 system and its capabilities. When connected to a CDTI with a digital moving map and other functions as presently being demonstrated in the MMI 5000 which is used in numerous test and validation programmes in Europe and elsewhere it is also providing Communications and Navigation functions. To date prototype STDMA/VDL Mode 4 systems has accumulated more than 60,000 flying hours on board Commercial, Military, General Aviation aircraft and Helicopters. In addition it is being used on board ships and airport vehicles. It is subject to standardisation for Maritime applications by IMO. MOPS are being developed by EUROCAE WG-51 Sub-Group 2 and will be available early 2000. Further details of the VDL Mode 4 system for aviation can be found in Draft ICAO SARPs version 6.0 and Manual on Detailed Technical Specifications for the VDL Mode 4 Data Link (Version 5.4.6)

Since VDL Mode 4 basically is a Digital Mobile Communications system it offers a range of other potential functions than those described in this document. This material has been limited to the basic ADS-B with some material on TIS-B, FIS-B and GNSS Augmentation. Some additional applications are also briefly mentioned.

Contents

E.1 Basic System Characteristics

E.1.1 Net Access Protocol

E.1.1.1 Net Management Concept

(See VDL Mode 4 Manual B.1)

VDL Mode 4 is an ATN-compliant communication system that can provide both broadcast and point-to-point services. The broadcast service may provide position information and so VDL Mode 4 naturally supports the Automatic Dependent Surveillance-Broadcast (ADS-B) application. It can also support a range of other applications, which use either the ATN-compliant or specific service functions of VDL Mode 4.

VDL Mode 4 operation is built up from the following fundamental elements:

1. A robust modulation scheme for encoding data in each slot.

2. A time-division multiple-access (TDMA) frame structure utilising a novel self-organising protocol.

3. A timing reference providing a unique marker for the start of each communications slot. The integrated timing concept (ITC) is used in VDL Mode 4.

4. Position information used to organise access to the slots.

5. A flexible message structure that can support a wide range of data transfer and broadcast protocols.

6. A slot selection function that determines when a station can access the channel and maintains information on the current and planned slot assignments.

7. A slot access management function, controlling the use of each slot. VDL Mode 4 supports:

   - autonomous access control, enabling stations to access the slot without requiring control by a master station;
   - a number of directed access schemes enabling stations to allocate slots for other stations and for a ground station to control overall slot access.

   The type of access scheme used will depend on the operational scenario.

8. A data-link service function which provides point to point and broadcast communications protocols.

9. A number of link management functions that support the communications connections with other stations and which provide access to data-link services on a wide range of channels. These include:

   - link establishment and maintenance;
   - Global Signalling Channels (GSCs) to provide a world-wide standard communication channel and a means of accessing other data link services;
   - a Directory of Services (DOS) to inform stations via the GSCs of supported services;
   - frequency management to allow access to support services operating on other frequencies.

VDL Mode 4 supports:

- autonomous access control, enabling stations to access the slot without requiring control by a master station;
- a number of controlled access schemes enabling stations to allocate slots for other stations and for a ground station to control overall slot access.

A major function of VDL Mode 4 is support for broadcast of position. Each mobile establishes “streams” of reservations for its position reports, where each stream consists of single-slot transmissions nominally separated by one minute. The transmissions are protected by reservations established using the periodic broadcast protocol.

E.1.1.1.1 Periodic Broadcast Protocol

(See VDL Mode 4 SARPs 3.3.11)

The most important autonomous access scheme for the overall operation of VDL Mode 4 is the “periodic broadcast” protocol which supports the broadcast of position and identity information by a station to all other stations in the vicinity and allows the system to operate effectively regardless of the presence of ground stations.

The protocol is illustrated in Figure E.1-1.

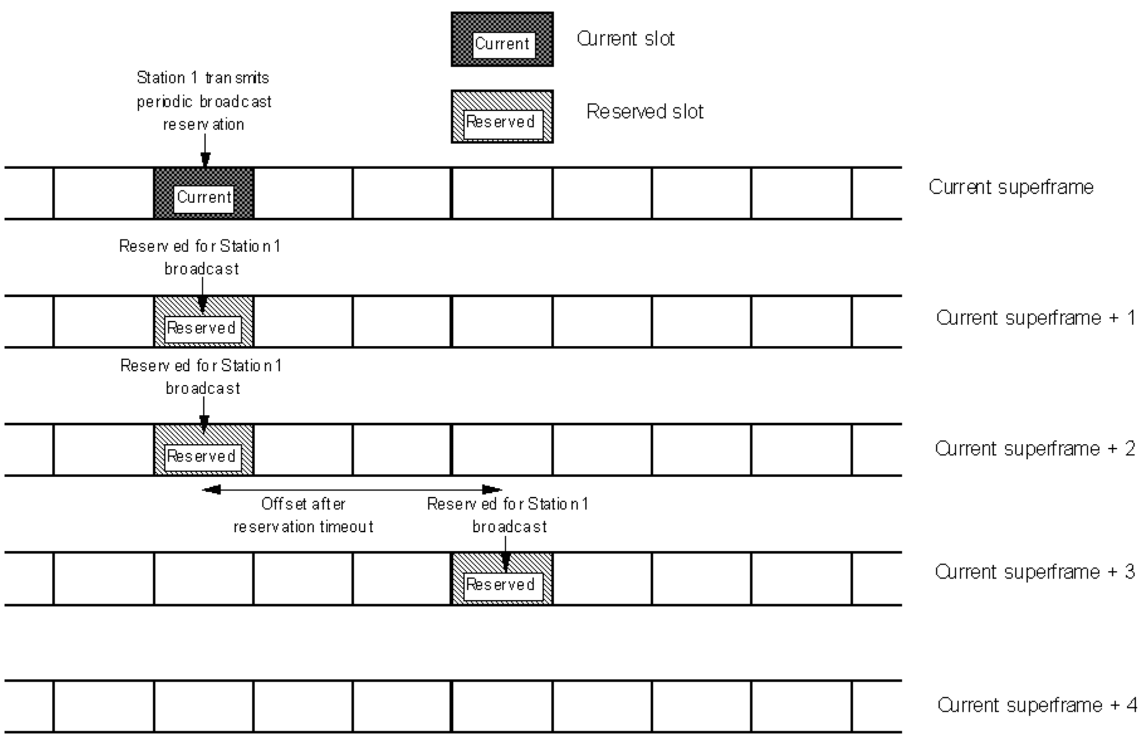


Figure E.1-1: Periodic broadcast

Each station transmits a periodic broadcast reservation burst that contains:

1. the station ID;
2. position information;
3. information controlling the periodic broadcast protocol:

   - the periodic time out value, which indicates for how many more super frames the reservation, will be held;
   - the periodic offset indicating the slot to which the reservation will move when the slot time out expires.

Each other station receiving this message will build up a “reservation table” by using this information and a time stamp derived from the slot in which the information was received. In the simplest form this allows all stations to build up picture of all other stations. The information also allows the other stations to control their own access to the data link as described below.

In the simple picture outlined above, all stations occupy a particular slot, or series of slots, in each super frame. When transmitting in a particular slot (indicated as the “current” slot in Figure E.1-1), they indicate a reservation for the same slot in the next super frame using the slot time out counter. They also indicate which slot they will be moving to in future super frames via the periodic offset parameter.

The assignment to slots is dynamic in two ways:

- Current stations change their slot at regular intervals between 3 and 8 minutes. The purpose of this is to ensure that as two aircraft fly closer to each other they do not continue to share the same slot or slots and garble each other’s position reports. In such situations, requiring aircraft to move randomly to new slots greatly reduces the probability of lost position reports.
- New stations arriving into coverage will continually enter the slot structure with their own broadcasts.

The selection of slots in the periodic broadcast protocol is a two-stage process:

- In the first stage, stringent slot selection criteria are applied so that a station A can only take a reserved slot if another station B, which is at least 250 nm away, is using the slot for a transmission which, despite the overlapping transmission from station A, will still be received by the intended destination because of favourable co-channel interference (CCI) conditions (see Section E.4.1 for further details). As there will be few reserved slots satisfying this criterion, station A is forced to look preferentially for unreserved slots. If station A finds just one slot by this process, it will use it - if it finds more than one, it will choose a slot randomly from the slots it has found.
- The second stage is that if, after going through the above process, station A is unsuccessful in finding suitable slots, it will apply less stringent criteria - it will be able to take a slot that a station B more than 250 nautical miles away is using for any broadcast transmission.

The overall effect of the two-stage process is to make the periodic broadcast protocol work preferentially with unreserved slots.

E.1.1.1.2 New Transmissions

Assuming that a new station has just entered into coverage and wishes to begin transmitting, the procedure without invoking the network entry protocol (see Section E.1.1.1.3) is as follows:

1. The new station listens to the global signalling channels until a complete super frame has been received (this will take 1 minute).

2. The information gained during this listening period is used to build up a reservation table, which contains a record of the data received for each slot. The station calculates the bearing and distance of each other station (this information is used to control access in the event that the new station must override the slot allocation of a more distant other station) and also assigns a time-out value which is a parameter that controls the deletion of old and inactive entries in the station directory.

3. The new station calculates the position of the “nominal slots” indicating where it would like to start transmitting data.

4. The new station chooses actual slots for its broadcasts using the slot selection method described in Section E.1.1.1.5 using candidate slots grouped around each nominal slot.

E.1.1.1.3 New Transmissions Using the Network Entry Protocol

(See VDL Mode 4 SARPs 3.5.5.3)

A Rapid Network Entry protocols to achieve a reduction in the length of any reporting gap by allowing a station to begin transmitting its position before it has acquired a complete slot reservation map is currently discussed in ICAO/AMCP/VSG. They are accomplished by defining three procedures:

- Half-slot transmissions;
- Big Negative Dither (BND) reservations;
- Plea-response transmissions.

Half-slot transmissions allow a station to make a short unannounced transmission in which it may place a reservation for subsequent position reports or request suitable slots from another station, without requiring knowledge of the current slot map. A station wishing to make a half-slot transmission will listen during a particular slot, then transmit in the second half of the slot if no other transmission has been detected after a half-slot period.

A Big Negative Dither (BND) reservation makes a reservation for a slot in the following super frame at a position behind that of the reservation in the current super frame. It can be used by stations, which have listened to the channel for a few seconds but have not yet built up a complete reservation table, and is useful for quickly moving newly acquired slots.

With the plea-response mechanism, a station wishing to perform network entry can acquire a number of slots in which to transmit by making a single half-slot plea transmission to other peer stations. A peer station will then respond with a number of slots which the new station can use for its own position reports. The new station can also use the BND reservations to move the slots it has been given to slots it considers more appropriate (with a more regular update period, for example).

Analysis of the need for a Rapid Network Entry scheme has been prepared and is presented in Appendix 3. The conclusion from that paper is that there is no operational need for it.

E.1.1.1.4 Slot Changing for Current Stations - Continuous Change of Slots

Stations maintain their slot reservation for a randomly chosen time between 3 and 8 minutes. Towards the end of the time-out period the station selects a new slot using the slot selection method described in Section E.1.1.1.5 using candidate slots grouped around each nominal slot. When a new slot has been found, the station indicates in the slot offset field of the periodic broadcast reservation burst which slot it will move to. When the current slot has timed out, the station moves to the new slot.

E.1.1.1.5 VDL Mode 4 Slot Selection

(See VDL Mode 4 SARPs 3.3.3.2, 3.3.4, 3.3.6.1 and 3.3.6.2)

An important feature of VDL Mode 4 is the method used to select slots for a new transmission or for placing reservations for future transmissions. When a channel is not busy, slot selection is straightforward since a slot that has not been previously reserved by an another station can be easily found. When a channel becomes busier such that unreserved slots are harder to find, VDL Mode 4 allows a station to use a slot previously reserved by another distant station. The result is that the coverage area of a station reduces in range gracefully as the channel becomes busy and there is no sudden reduction in the ability to communicate. A further advantage is that all stations carry out slot selection and there is no reliance on a ground station to carry out channel resource management.

Figure E.1-2 illustrates the slot selection process. The process has the following stages:

- An application wishing to send data or to place a reservation to send data in the future first specifies a range of candidate slots from which a slot will be chosen.

- The station then derives a list of available slots. The available slots are a subset of the candidate slots and consist of slots that are either unreserved or which, although previously reserved by another station, can be made available for use because of special selection rules. Note that before finally selecting a slot, it is important to derive a number of available slots, typically 4, in order to reduce the possibility of more than one station selecting the same slot (for example, if there were only one unreserved slot among the candidate slots, there would be a high chance of more than one station choosing that slot).

- A slot is selected randomly from the available slots.

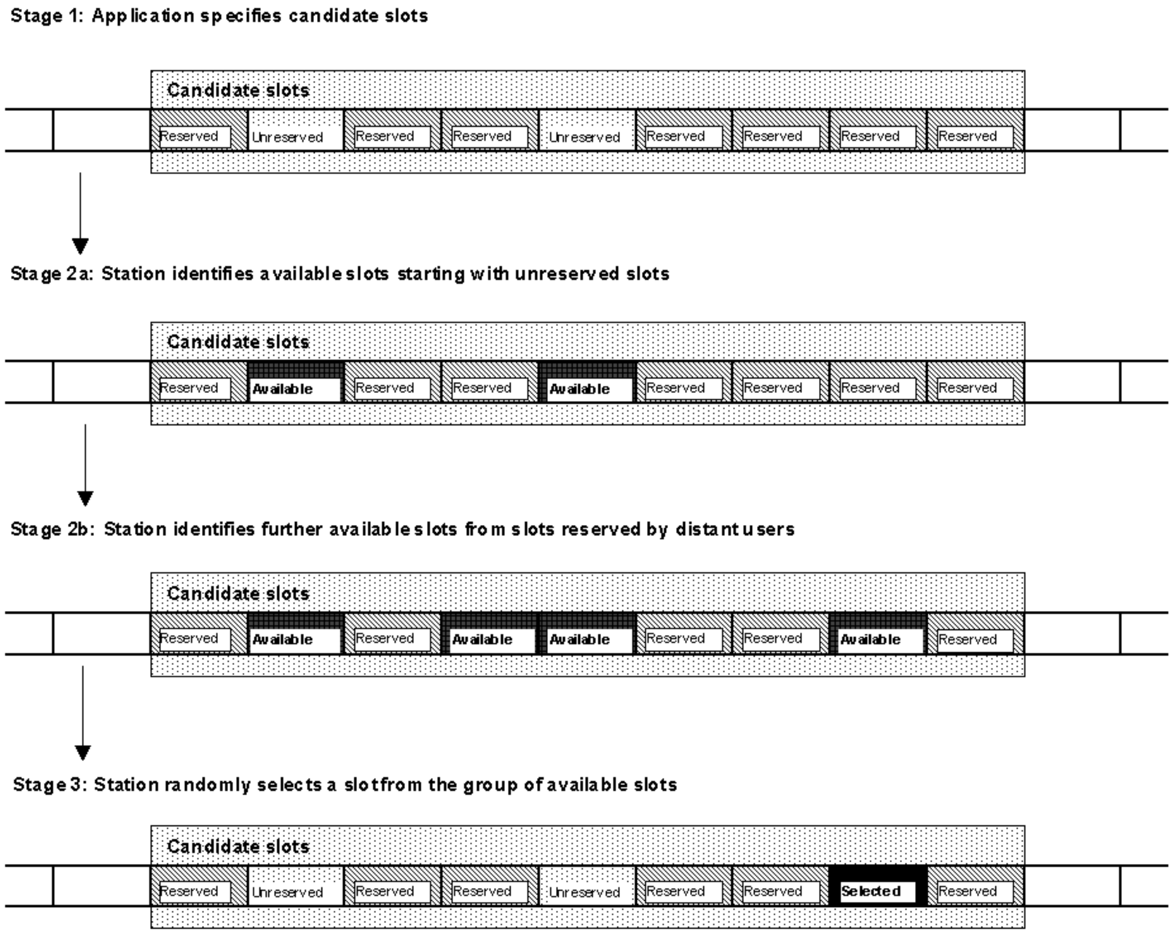


Figure E.1-2: VDL Mode 4 slot selection

E.1.1.1.6 Other Channel Access Protocols

(See VDL Mode 4 Manual B.8.2)

In addition to the periodic broadcast protocol, VDL Mode 4 supports a range of other access protocols that support a range of broadcast and end-to-end communication protocols.

E.1.1.1.6.1 Incremental Broadcast Protocol

(See VDL Mode 4 SARPs 3.3.12)

The incremental broadcast protocol is used by applications that must broadcast data over a short period of time, typically within the same super frame. Each data burst broadcast can also be used to reserve a slot for the next broadcast. The protocol is illustrated in Figure E.1-3.

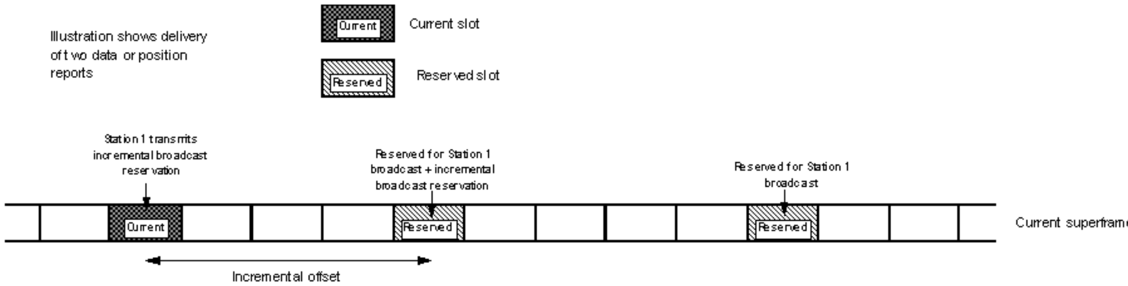


Figure E1-3: Incremental broadcast

When transmitting a burst containing an incremental broadcast reservation, the station specifies the following parameters:

- incremental offset (value 1 to 255): the reservation for the next data broadcast is offset by 8 x incremental offset from the current slot.

The subfields shall be as defined in Table E.1-1.

Table E.1-1: Incremental broadcast reservation field encoding

Subfield	Range	Encoding	Definitions
incremental offset (io)	1 to 255		io identifies a slot relative to the first slot of the transmission

The incremental broadcast protocol shall implement the system parameters defined in Table E.1-2.

Table E.1-2: Incremental broadcast VSS system parameters

Symbol	Parameter Name	Minimum	Maximum	Recommended Default	Increment
V21	Nominal incremental period	960/M1 sec	60480/M1 sec	1.0 sec	0.1 sec
V22	Maximum incremental dither range	720/(V21* M1)	MIN(1-240/(V21*M1), 61200/(V21*M1) - 1)	0.75	0.01

Note: The periodic broadcast and incremental broadcast reservations can be combined e.g. for transmission of TCP and TCP+1 data on demand. When the periodic broadcast timer (TV11) is greater than 3, this will enable a station to reserve a fourth slot up to 2048 slots in the future as well as three slots in the subsequent super frames. A station may therefore use the opportunity presented by a combined periodic broadcast and incremental broadcast to reserve a slot for a different user which happens to be in the random access queue or to improve net entry performance by reserving both in the next super frame (periodic broadcast) and this super frame (incremental broadcast).

E.1.1.1.6.2 Unicasted Request Protocol

(See VDL Mode 4 SARPs 3.3.14)

A station that requires a response from another station uses the unicasted request protocol. Figure E.1-4 illustrates the protocol. Station 1 requests information from station 2, simultaneously issuing a reservation for station 2's response.

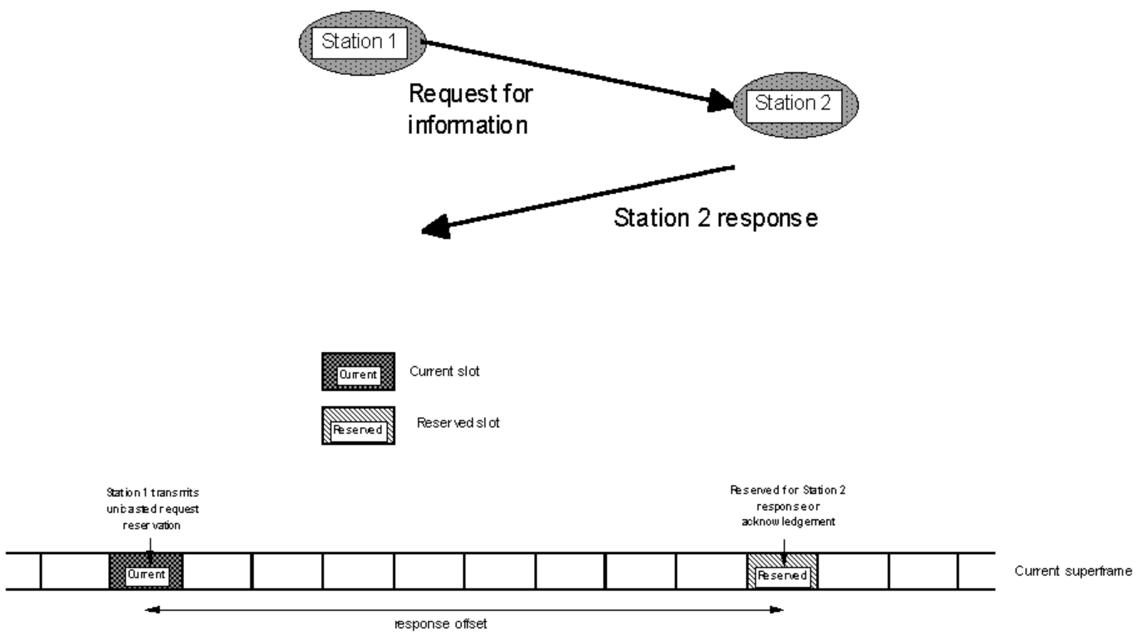


Figure E.1-4: Unicasted request

When transmitting a burst containing a unicasted request reservation, the station specifies the following parameters:

- destination address: this identifies the station from which a response is requested;
- frequency: this determines the channel on which on which a response is required;
- response offset (value 0 to 4095): the reservation for a response is offset by an amount equal to the value of the response offset from the current slot.

A variation of the unicasted request protocol also allows a station to reserve a slot for a later transmission by the same station to a destination station. This is controlled by the setting of the source/destination (sdf) flag.

E.1.1.1.6.3 Information Transfer Request Protocol

(See VDL Mode 4 SARPs 3.3.15)

The information transfer request protocol is used for an application to obtain a data series from another application. Slots are reserved for transmission of the requested information and for an acknowledgement by the requesting application. The protocol is illustrated in Figure E.1-5.

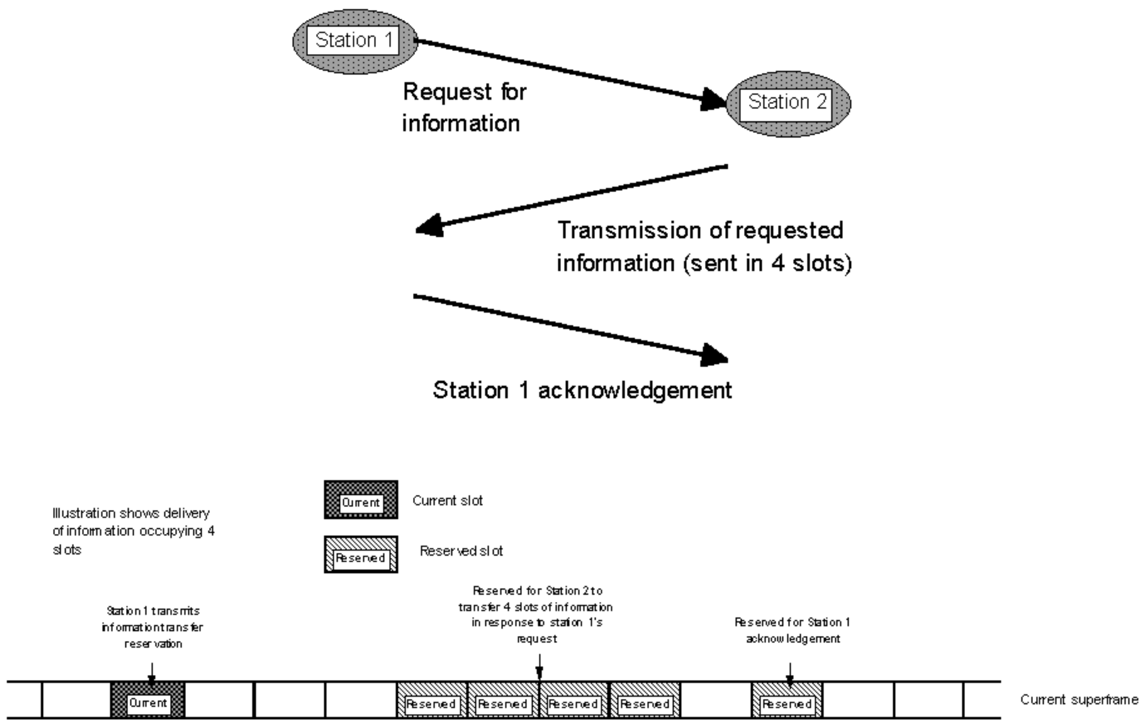


Figure E.1-5: Information transfer request

When transmitting a burst containing an information reservation, the station specifies the following parameters:

- frequency: the station can specify the channel on which the information transfer should take place;
- destination address: this identifies the station from which a response is requested;
- response offset (value 0 to 4095): this indicates the start of the reserved block for the response relative to the current slot;
- length (value 0 to 511): this indicates the length of the response block;
- acknowledgement offset (value 0 to 127): the reservation for an acknowledgement to the information block by the requesting station is offset by an amount equal to the value of the acknowledgement offset from the current slot.

E.1.1.1.6.4 Directed Request Protocol

(See VDL Mode 4 SARPs 3.3.16)

A directed request is used in a similar way to the periodic broadcast protocol as a means of obtaining regular broadcasts. However, a single station (probably a ground station) carries out the allocation of slots. The protocol might be used to control the broadcasts of a group of stations in a geographical region under ground station control. The protocol is illustrated in Figure E.1-6.

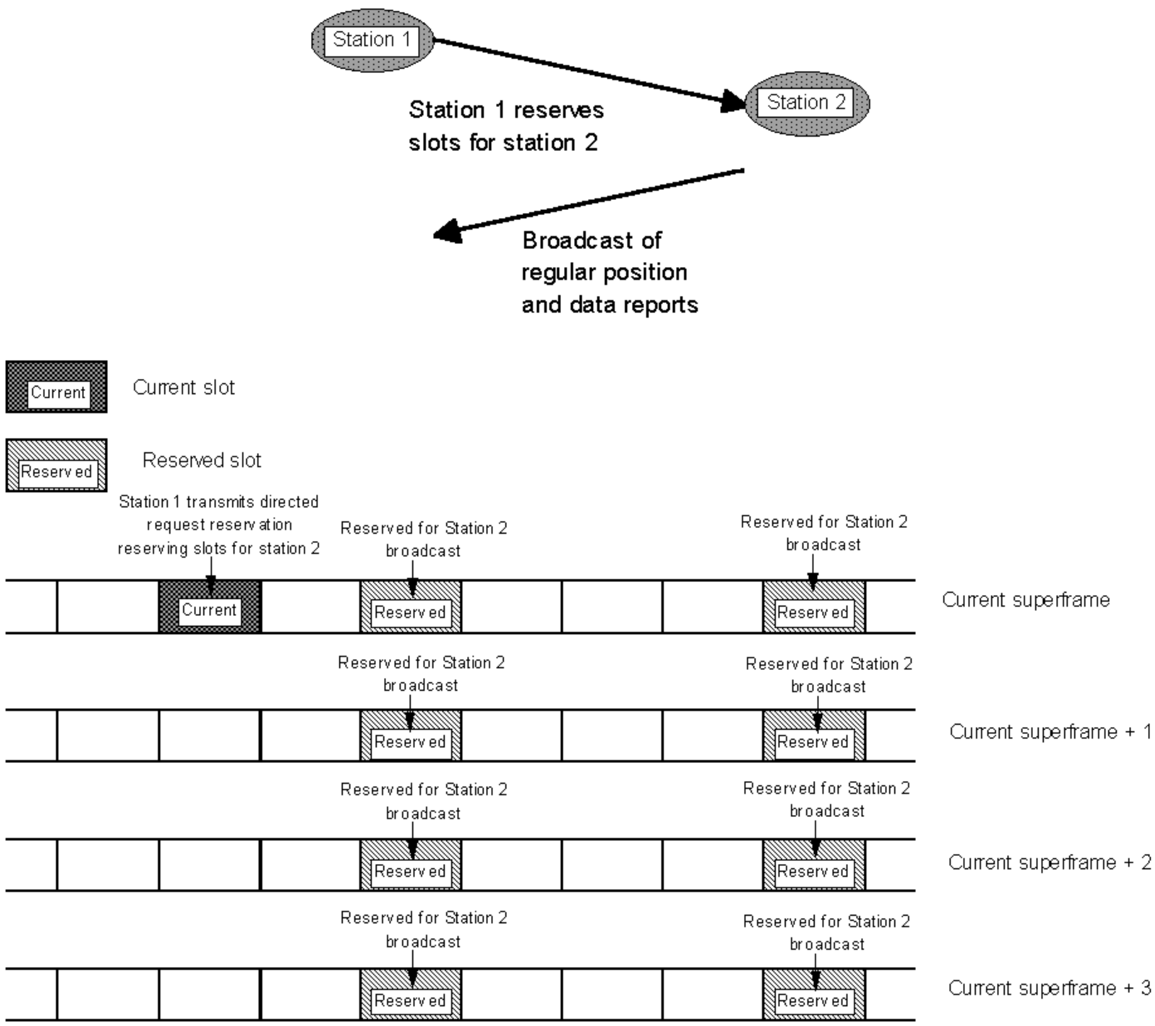


Figure E.1-6: Directed request

When transmitting a burst containing a directed request reservation, the station specifies the following parameters:

- frequency a, frequency b: the station can direct other stations to alternate between two frequencies or to just use one frequency;
- destination address: this identifies the station which is being directed;
- directed offset (value 2 to the length of a super frame - 1): this indicates the first slot in which the station should broadcast;
- directed rate (value 1 to 60): this indicates the number of reservations to be made per super frame;
- directed time-out (value 0 to 15): this indicates the number of super frames for which the reservation is maintained;
- override bit (value 0 or 1): this indicates whether a new reservation placed by a ground station will override all previous reservations placed by the same ground station.

Directed reservations can be cancelled by setting the directed time-out to 15.

E.1.1.1.6.5 Random Access Protocol

(See VDL Mode 4 SARPs 3.2.7)

Random access is used by applications when there is no prior reservation. The protocol is illustrated in Figure E.1-7.

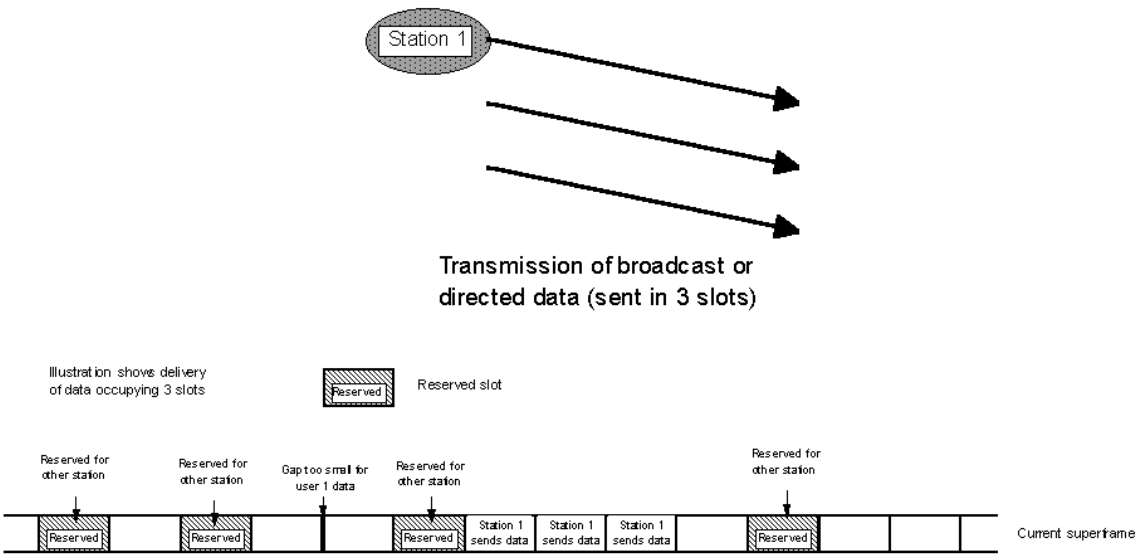


Figure E.1-7: Random access

E.1.1.1.6.6 Fixed Transmission Protocol

(See VDL Mode 4 SARPs 3.3.8)

Ground stations can be programmed to transmit at pre-defined times regardless of reservations on the channel. For example, this allows a ground station to transmit regular data uplinks to support Directory of Service messages (DoS), DGNSS, FIS-B, TIS-B, etc. This mode of operation is supported by ground quarantining, which prevents mobile users reserving slots adjacent to ground station reservations under certain circumstances.

E.1.1.2 End State Protocol

Latest information shown in Appendix A.

E.1.1.3 Relationship of Test Circumstance to End State

See Section E.8.

E.1.2 Waveform

E.1.2.1 Channel Frequencies and Modulation Technique

E.1.2.1.1 Channel Frequencies

(See VDL Mode 4 SARPs 1.4.1)

A mobile VDL Mode 4 transmitter is capable of tuning to any of the 25 kHz channels from 112.000 MHz through 136.975 MHz. A mobile VDL Mode 4 receiver is capable of tuning to any of the 25 kHz channels from 108.000 MHz through 136.975 MHz. A ground station is capable of operating on its assigned 25 kHz channel within the 108.000 - 136.975 MHz band.

The differences in tuning ranges for mobile stations, with respect to transmit operations versus receive operations, enables uplink transmissions in a protected band. Mobile stations may tune to these channels for receive operations, but are prevented from generating accidental transmissions.

E.1.2.1.2 Modulation Technique

(See VDL Mode 4 SARPs 2.3)

The main modulation scheme foreseen for VDL Mode 4 is Gaussian Filtered Frequency Shift Keying (GFSK), which is a continuous-phase, frequency shift keying technique using two tones and a Gaussian pulse shape filter. The D8PSK scheme could possibly also be used if found to be an attractive alternative.

E.1.2.2 Channel Rate and Bit Structure

(See VDL Mode 4 SARPs 3.2)

Binary ones and binary zeros are generated with a modulation index of 0.25 ± [0.03] and a BT product of 0.28 ± [0.03], producing data transmission at a bit rate of 19,200 bits/sec ± 50 ppm.

In VDL Mode 4, channel time is divided into fixed length time slots. A “super frame”, which is an important term used in the VDL Mode 4 channel management, consists of a group of slots that span a period of 60 seconds. If GFSK modulation is used in VDL Mode 4, the super frame contains 4500 slots (equivalent to 75 slots per second). This is illustrated in Figure E.1-8.

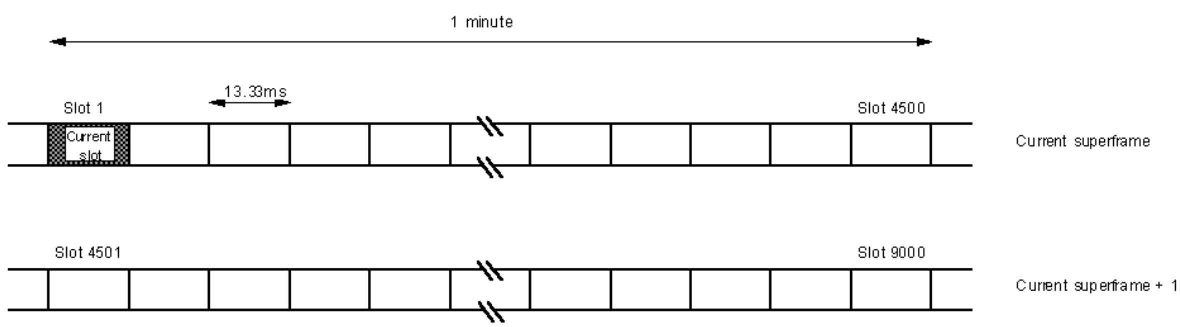


Figure E.1-8: GFSK super frame

Each time slot is accessible for receiving or transmitting by any station communicating on the data link. One position (ADS-B) report will occupy one time slot on the data link. Other transmissions can occupy more than one slot dependent on the application.

There are 256 bits, or 32 octets (bytes) available for transmission in each slot, although some of these bits are not available for data as they are required for message management functions.

E.1.2.3 Synchronization and Preamble Characteristics

(See VDL Mode 4 SARPs 2.1.3.2)

VDL Mode 4 requires time synchronisation for basic station access without mutual interference. The time standard for VDL Mode 4 is Universal Co-ordinated Time (UTC). The time is primarily based on GNSS[E1] but other sources may be used as long as they can be related to UTC. For GFSK modulation, the start of every 75th slot is aligned to an UTC second for mobile units. A change to align the mobile stations to the UTC minute is raised in the ICAO VSG. The need to co-ordinate and align the VDL Mode 4 ground stations to the UTC minute has been recognised and decided upon.

The first segment of the training sequence is the transmitter power stabilisation (stage A in Figure E.1-9), which consists of 16 symbols each representing 1.

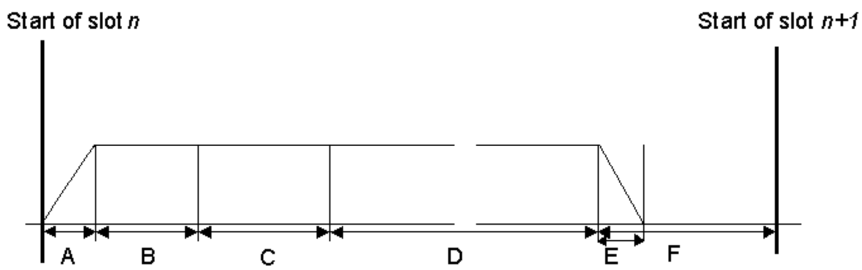


Figure E.1-9: Transmission timing for a single-slot message

Legend: A= 16 bits; B= 24 bits; C= 0 bit; D=192 bits; E=300 micro sec; F= 24 bits ~203 nm.

The second segment of the training sequence (stage B in Figure E.1-9) is the 24-bit binary sequence 0101 0101 0101 0101 0101 0101, transmitted from left to right immediately before the start of the data segment (stage D in Figure E.1-9).

The transmission of the first bit of data (stage D in Figure E.1-9) starts 40 bit intervals (approximately 2083.3 microsecond) ± 1 microsecond after the nominal start of transmission (region C is zero length for GFSK modulation).

E.1.2.4 Message Structure and Coding

(See VDL Mode 4 SARPs 3.3.2)

VDL Mode 4 bursts conform to ISO 3309-frame structure except as specified in Table E.1-3.

[E1] GNSS data may be derived from GPS, GPS/GLONASS and/or other GNSS systems.

Table E.1-3: Burst format

Description	Octet	Bit number							
		8	7	6	5	4	3	2	1
Flag	-	0	1	1	1	1	1	1	0
reservation ID (rid), version number (ver)	1	s_{27}	s_{26}	s_{25}	ver_3	ver_2	ver_1	rid	1
	2	s_{24}	s_{23}	s_{22}	s_{21}	s_{20}	s_{19}	s_{18}	s_{17}
source address (s)	3	s_{16}	s_{15}	s_{14}	s_{13}	s_{12}	s_{11}	s_{10}	s_9
	4	s_8	s_7	s_6	s_5	s_4	s_3	s_2	s_1
message ID (mi)	5	In_k	mi_k	. . . . . .		mi_4	mi_3	mi_2	mi_1
	6								
Information	6 - n-5				. . . .				
	n-4								
reservation data (rd)	n-3		in_1	rd_k		. . . . . .			
extended reservation ID (erid)	n-2	$erid_k$		. . . . .		$erid_1$			rd_1
CRC (c)	n-1	c_{16}	c_{15}	c_{14}	c_{13}	c_{12}	c_{11}	c_{10}	c_9
	n	c_8	c_7	c_6	c_5	c_4	c_3	c_2	c_1
Flag	-	0	1	1	1	1	1	1	0

. . . . Denotes variable length field

Details of the message fields can be obtained from Annex to SARPs Working Material, 9 July 1999.

E.1.2.5 Measured MTL Response with Supporting Analysis

MTL is not defined in VDL Mode 4 SARPs.

E.1.3 Messages and Reports

E.1.3.1 Message Types and Broadcast Rates

E.1.3.1.1 Message Structure

(See VDL Mode 4 Manual B.6)

VDL Mode 4 provides a library of message types that can be used to support a wide variety of data transfers and broadcasts. Figure E.1-10 illustrates the message structure.

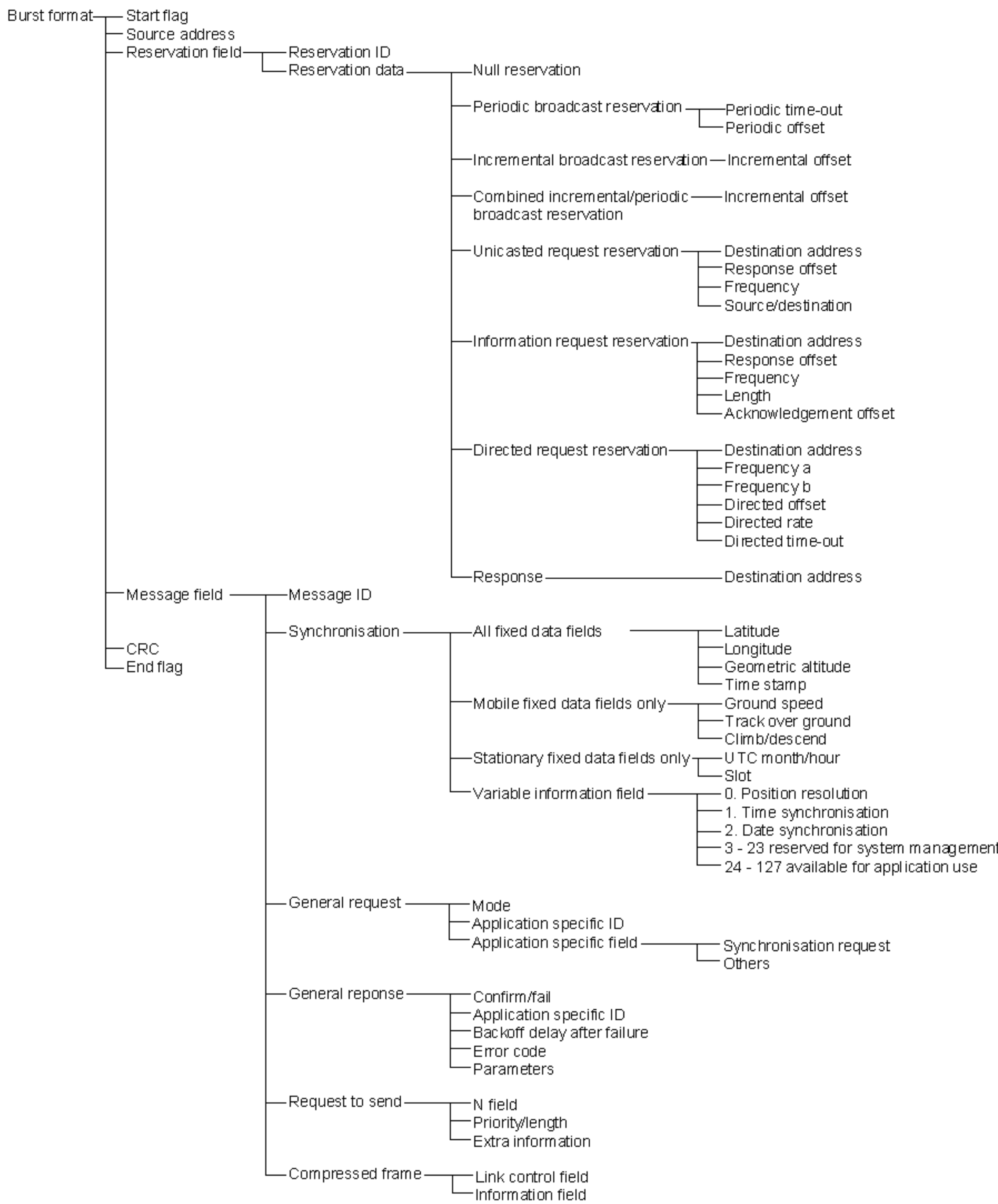


Figure E.1-10: VDL Mode 4 burst structure

Note. The above message content may be subject to changes as a result of practical experience and continued work on the operational concept and on-going review in ICAO VSG and EUROCAE WG-51 SG2.

The flexible message structure allows a station to transmit messages whilst simultaneously placing reservations for future slot usage.

E.1.3.1.2 Synchronization Burst Format

Synchronisation bursts consist of both a fixed and a variable part, where the variable part can contain different information according to the particular message or application required.

E.1.3.1.2.1 Fixed Data Field

(See VDL Mode 4 SARPs 3.5.2.2)

The fixed data field for a mobile synchronisation burst is defined in Table E.1-4. A similar fixed data field is defined for a ground station synchronisation burst. (Note: - the formats of the mobile and ground station synchronisation bursts are currently undergoing review by the VDL Mode 4 Validation Sub-Group (VSG).)

Table E.1-4: Fixed part of mobile station synchronisation burst

Description	**Octet**	**Bit number**							
		8	7	6	5	4	3	2	1
autonomous/directed flag (a/d) baro/geo altitude (b/g) CPR Format even/odd (cprf) position uncertainty (nucp)	5	$nucp_4$	$nucp_3$	$nucp_2$	$nucp_1$	cprf	b/g	a/d	0
latitude (lat)	6	lat_8	lat_7	lat_6	lat_5	lat_4	lat_3	lat_2	lat_1
longitude (lng)	7	lng_{12}	lng_{11}	lng_{10}	lng_9	lat_{12}	lat_{11}	lat_{10}	lat_9
	8	lng_8	lng_7	lng_6	lng_5	lng_4	lng_3	lng_2	lng_1
data age (da)	9	$balt_{12}$	$balt_{11}$	$balt_{10}$	$balt_9$	da_4	da_3	da_2	da_1
base altitude (balt)	10	$balt_8$	$balt_7$	$balt_6$	$balt_5$	$balt_4$	$balt_3$	$balt_2$	$balt_1$
time figure of merit (tfom) information field ID (id)	11	$tfom_2$	$tfom_1$	id_6	id_5	id_4	id_3	id_2	id_1
information field (in)	12	in_{54}	in_{53}	in_{52}	in_{51}	in_{50}	in_{49}	in_{48}	in_{47}
	13	in_{46}	in_{45}	in_{44}	in_{43}	in_{42}	in_{41}	in_{40}	in_{39}
(See Appendix 3 for additional	14	in_{38}	in_{37}	in_{36}	in_{35}	in_{34}	in_{33}	in_{32}	in_{31}
Information on ADS-B)	15	in_{30}	in_{29}	in_{28}	in_{27}	in_{26}	in_{25}	in_{24}	in_{23}
	16	in_{22}	in_{21}	in_{20}	in_{19}	in_{18}	in_{17}	in_{16}	in_{15}
	17	in_{14}	in_{13}	in_{12}	in_{11}	in_{10}	in_9	in_8	in_7
	18	in_6	in_5	in_4	in_3	in_2	in_1		

E.1.3.1.2.2 Variable Data Field

(See VDL Mode 4 SARPs 3.5.2.3)

The variable data field is available to carry additional information as may be required by another user or application - for example, downlinked data from aircraft systems. The content and format of the variable data field are identified by the information field ID (id). The format of the variable data field corresponding to a given id is as specified in the appropriate application standard. See examples in Appendix 2.

E.1.3.1.2.3 Broadcast Rates

(See 'Performance and Capacity of ADS-B using VDL Mode 4', G. Frisk, Swedish CAA and 'VDL Mode 4 Validation Procedures and Control Document')

Typical ADS-B update rates using the periodic broadcast protocol have been provided by simulations with Core European and L.A. Basin Scenarios. The Core European Scenario is defined in the VDL Mode 4 Validation Procedures and Control Document (VPCD). The update periods are based on those given in the ICAO Manual of ATS Data Link Applications, i.e. 10s for en-route and 5s for terminal areas. The results of currently completed simulations are shown in Table E.1-5.

Table E.1-5: Simulation of VDL Mode 4 slot utilisation for three traffic scenarios

Scenario	**Core European**	**LA Basin**	**Extended LA Basin**
No. of channels	2 GSCs	2 GSCs	2 GSCs
No. of aircraft	838	743	1000
Update period	5 s in terminal areas 10 s en-route	7.5 s	7.5 s in LA Basin 10 s en-route
Overall load	2 x 85%	2 x 67%	2 x 84%
Slots with single transmissions	99.5% (excl. of CCI effects)	99.8% (excl. of CCI effects)	97.9% (excl. of CCI effects)
Slots with multiple transmissions	38 of 7658	12 slots of 5980	160 of 7522

E.1.3.2 Relationship Between Message Receptions and Output Reports

There is essentially a one-to-one relationship between messages and output reports in VDL Mode 4. However, some data is only transmitted infrequently (e.g. aircraft flight number). Other data requires more than one report to be transmitted (e.g. unambiguous position - a single position report provides the position within a [600 nm X 600 nm] region).

E.1.3.3 Relationship Between Required Report Update Rates and Supported Applications

(See 'Performance and capacity of ADS-B using VDL Mode 4', G. Frisk, Swedish CAA)

ADS-B MASPs define required received update rates for both 95% and 99% message delivery probabilities for the following applications:

- Enhanced See and Avoid
- Conflict and Collision Avoidance
- Separation assurance and sequencing
- Flight-path de-conflict planning
- Enhanced Operations for En-route Air-to-Air
- Improved Terminal Operations in Low Visibility
- Simultaneous Parallel Approaches
- Enhanced Surface Surveillance for Controllers
- Airport Surface Navigation and Operations
- ADS-B Surveillance in Non-Radar Airspace

Low density airspace: Simulation studies have shown that VDL Mode 4 can satisfy the MASPS required update rates for all of the above applications using only two channels (the Global Signalling Channels) in low density airspace including uplink of DGNSS/GRAS, TIS-B FIS-B and DoS (See Attachment 1).

In Future High Density Airspace - Core Europe and Future LA Basin traffic scenarios the two GSCs has to be complemented by locally assigned additional channel(s) (See Attachments 1.1. and Appendix A under separate cover.) Preliminary analysis indicates that 1 Tx and 3 Rx will be sufficient to handle those scenarios. Traffic scenarios for 2015 and beyond will require an additional local channel. Current productions units has hardware with 4 Rx.

E.1.4 Spectrum Issues

E.1.4.1 Channel Availability

(See 'Performance and capacity of ADS-B using VDL Mode 4', G. Frisk, Swedish CAA)

Two channels are required for ADS-B operation, and these are the Global Signalling Channels, assigned world-wide. Additional channels should be assigned locally as required.

E.1.4.2 EMC Effects of ADS-B on Other Systems

VDL Mode 4 meet required spectrum masks defined by ICAO for VDL, revised at AMCP/6 in March 1999, to ensure that there is a minimum of EMC interference caused to other systems. It also complies with the European Telecommunications Standards Institutes (ETSI 300 113) Technical Characteristics and Test Conditions for Mobile Services. The appropriate authorities tasked to ensure that it does not cause interference will also certify all VDL Mode 4 equipment.

Experience to date with VDL Mode 4 equipment shows that there are no adverse interference effects.

E.1.4.3 EMC Effects of Other Systems on ADS-B

Any VHF channel used for VDL Mode 4 ADS-B will need the appropriate protection from interference.

E.1.5 Link Budget Parameters

E.1.5.1 Power

The VDL Mode 4 synthesized radios can operate with output power settings in steps of 1 W with a range of 1-25 W. The likely power output from airborne mobile units is 10 W, for airport ground vehicles 1-3 W and from the base stations 10-25 W.

E.1.5.2 Sensitivity-MTL

-103dBm for BER=10^{-4}

E.1.6 Role of a Ground Station

A VDL Mode 4 ground station can be used to enable additional services and functions to the VDL Mode 4 system. A ground station can be configured in different ways depending upon the desired functions. A fully equipped ground station is configured as illustrated below.

ADS-B and TIS-B	**Timing Source**	**FIS-B**	AOC
DGNSS/GRAS	**Secondary Navigation**	CPDLC	GRq and **DoS**

Legend: Transmit/Receive **Transmit only**

Note: It is important to understand that the proposed function of a ground station do not include the slot allocation mechanism. A ground station is used to transmit and receive information. The ground station can also be used to control the report rate and frequency(ies) to be used, etc.

E.1.7 Differences in Test State and End State Configurations

Test state equipment is not known. PMEI/ADSI and iiMorrow should provide aircraft architectures related to the Test State. Preliminary end state architectures are presented in Section E.2.3.1 and Figures E.2-9 through E.2-11.

E.2 System Overview

The conceptual capabilities of VDL Mode 4 are illustrated in the following figure.

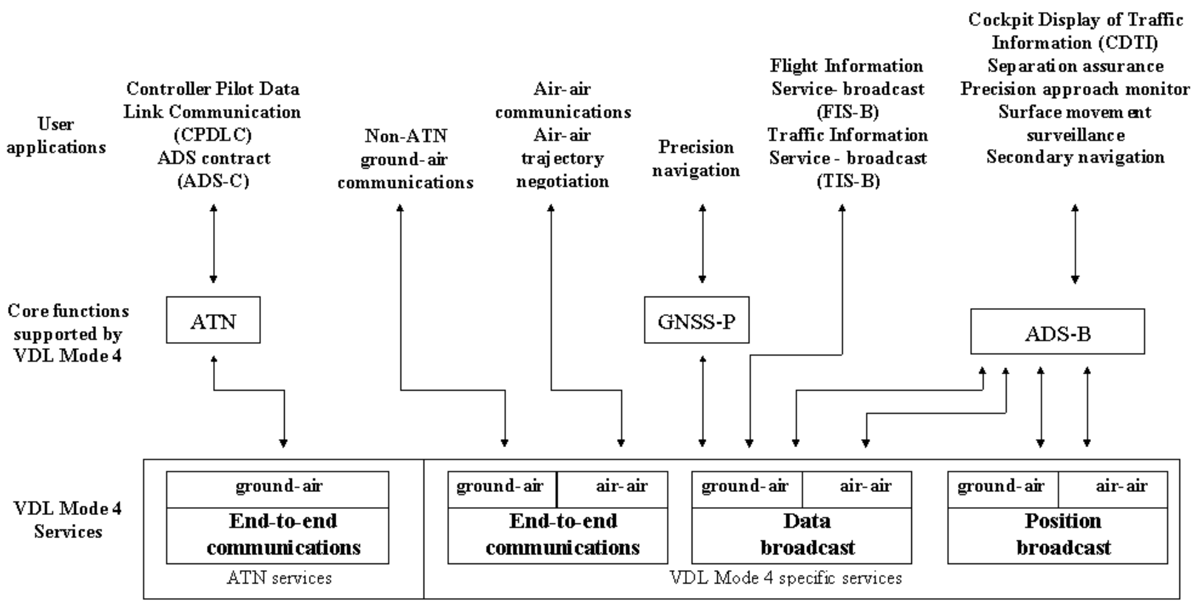


Figure E.2-1: VDL Mode 4 Systems overview

E.2.1 Intended Surveillance Role

(See ADS-B MASPs)

VDL Mode 4 can support all foreseen CNS/ATM applications including those described in Section E.1.3.3. and the above table with two or more 25 kHz channels.

This includes long-range air-to-air applications because of the low attenuation of the VHF signal. Communications can easily be maintained over distances of several hundred nautical miles with low power transmitters.

ADS-B

The ADS-B function uses the VDL Mode 4 synchronisation burst message formats to broadcast regularly an aircraft or vehicle's identity, position, altitude, time and vector information for use by other users, both mobile and on the ground. Because position reporting is an integral part of communications management in VDL Mode 4, ADS-B can be supported very simply and at low cost.

ADS-B supports many mobile-mobile surveillance applications such as Cockpit Display of Traffic Information (CDTI), situation awareness and station keeping. When the VDL Mode 4 system also includes ground stations it is also able to support applications such as Advanced Surface Movement Guidance and Control Systems (A-SMGCS), enhanced ATC surveillance, Search and Rescue (SAR) co-ordination, etc.

Figure E.2-2 shows how ADS-B can be used to provide ground surveillance functions through the use of a network of ground stations. Local servers at ground stations passively collect surveillance information from mobiles and send this information to a network service for transmission to the end application (e.g. to support the surveillance air picture).

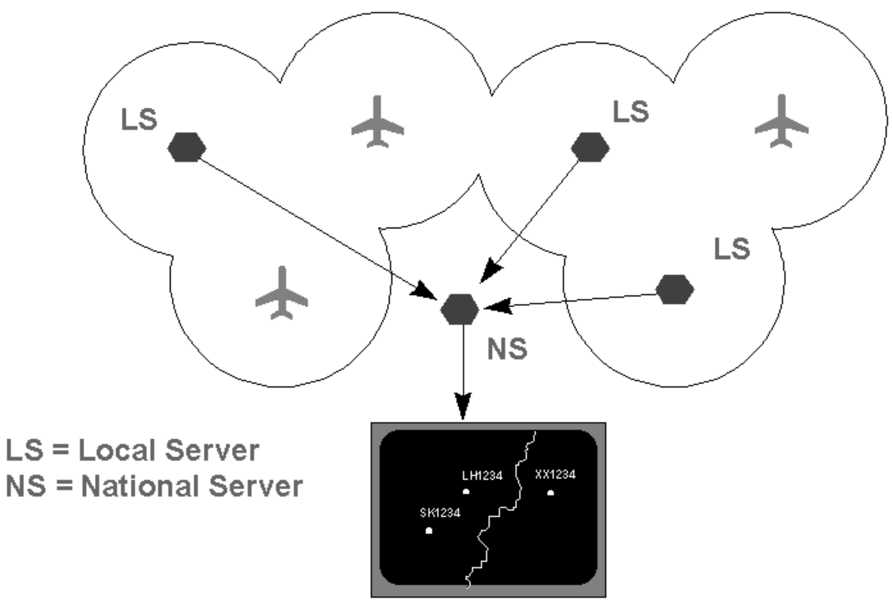


Figure E.2-2 Ground network support for ADS-B

ADS-B has several potential advantages, including:

- Accuracy: Modern aircraft (and particularly those equipped with GNSS) may be able to determine, and hence report, their own position to higher accuracy than surveillance radar.

- Greater information: As well as current position, an aircraft can report its velocity (true track, airspeed, etc) and long term intent (e.g. cleared flight level, next waypoint). This additional information will have significant benefits to the ATC computers that monitor the aircraft, e.g. for conflict prediction.

- Gate-to-gate operations: ADS-B systems will provide surveillance reports during any phase of flight. Currently, a range of different surveillance systems are used depending on whether the aircraft is on ground, in precision approach, in en-route airspace or in oceanic areas.

- Flexibility: The reporting rate of ADS-B is not fixed. An aircraft can report surveillance data at any rate, e.g. once every 10s, 5s or even 1s. The rate can be adjusted to suit the operating environment: for example a higher reporting rate may be required in more dynamic regions such as the TMA or airport surface in low visibility. Changes in the reporting rate may be initiated by the radio itself or by a ground station that can instruct the airborne transponder to change its reporting rate.

- Cost: VDL Mode 4 ADS-B systems are expected to offer a low cost surveillance solution because of the relatively low cost ground stations and multipurpose aircraft equipment.

Cockpit Display of Traffic Information (CDTI)

One of the greatest benefits of VDL Mode 4, and a natural extension of its ADS-B capability, is that it provides a pilot with situation awareness using a ‘Cockpit Display of Traffic Information’ (CDTI). This means that a display in the cockpit can show the pilot the positions of all other aircraft in the vicinity with a range of up to 200 nautical miles, as illustrated in Figure E.2-3.

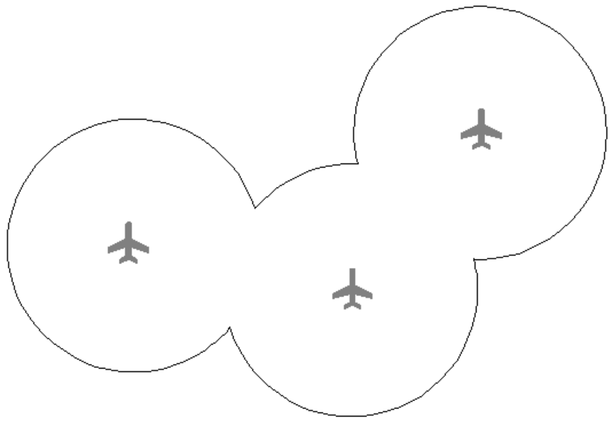
Ground movement surveillance

Surface Movement Guidance and Control Systems (SMGCSs) are becoming essential components of airport control systems and, as illustrated in Figure E.2-4, require the exchange of surveillance and other types of data between all users in the vicinity of the airport.

VDL Mode 4 provides a flexible communication, surveillance and navigation backbone which supports the operation of an airports SMGCS, providing for example

- ADS-B data to support controller surveillance systems;
- CDTI, illustrated in Figure E.2-5, to support mobile user surveillance, guidance and collision avoidance;
- a two-way data link to support automated controller-pilot communication;
- uplinked GNSS Augmentation to support aircraft navigation in poor visibility;
- a communications link to assist airline operators in the surveillance and control of support vehicles.

Using VDL Mode 4, essentially the same equipment can be installed for all users on the airport surface, e.g. wide-bodied commercial aircraft, small GA aircraft, ground vehicles etc. Whilst some certification and equipment requirements will differ, the basic functionality will be the same.



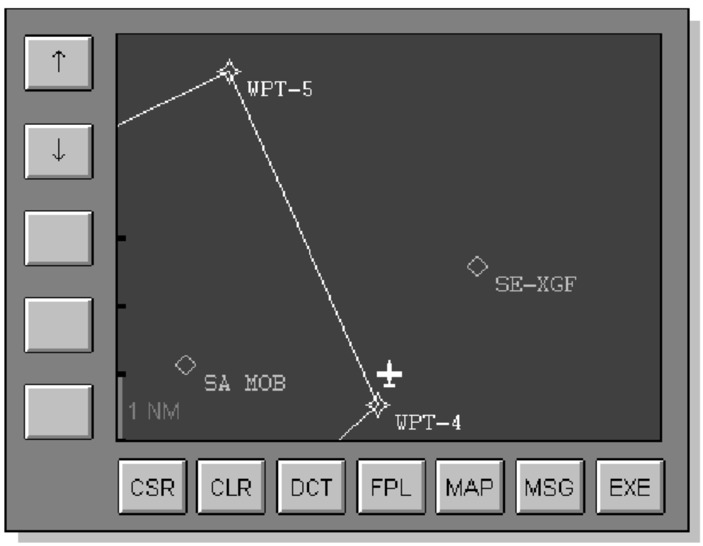


Figure E.2-3: Cockpit Display of Traffic Information (CDTI)

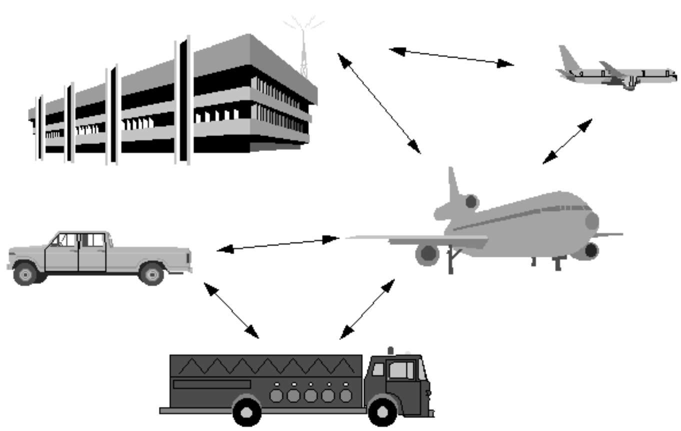


Figure E.2-4: Examples of data passed between all users in SMGCS

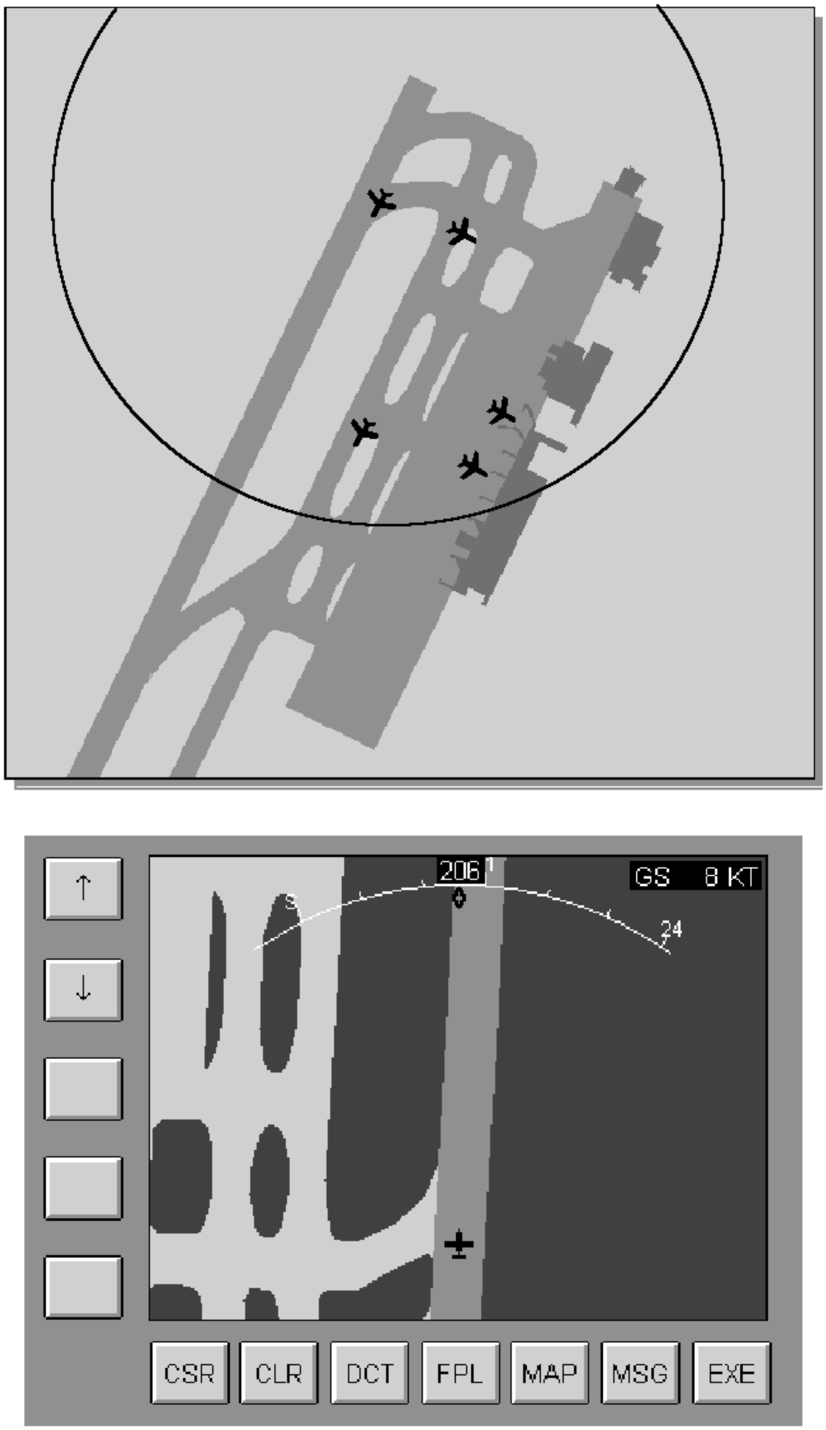


Figure E.2-5: CDTI for ground surveillance

Ground-based surveillance

The ADS-B application of VDL Mode 4 can be used with ground stations to provide ground surveillance either as an alternative to radar or working in conjunction with existing radar systems as illustrated in Figure E.2-6. A combination of ADS-B, VDL Mode 4 communication services and existing radar can also be used to enhance airborne surveillance by uplinking position reports for mobiles not equipped with VDL Mode 4. This is likely to be particularly useful in a transition period when not all aircraft are equipped.

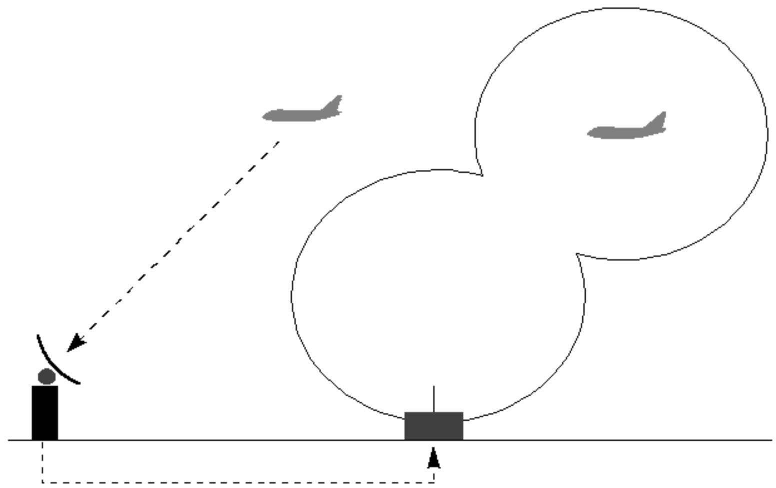


Figure E.2-6: Ground based surveillance provided by ADS-B and radar

An illustration of the existing and New ATM Surveillance Environment with ADS-B implemented is presented in Figure E.2-7 below.

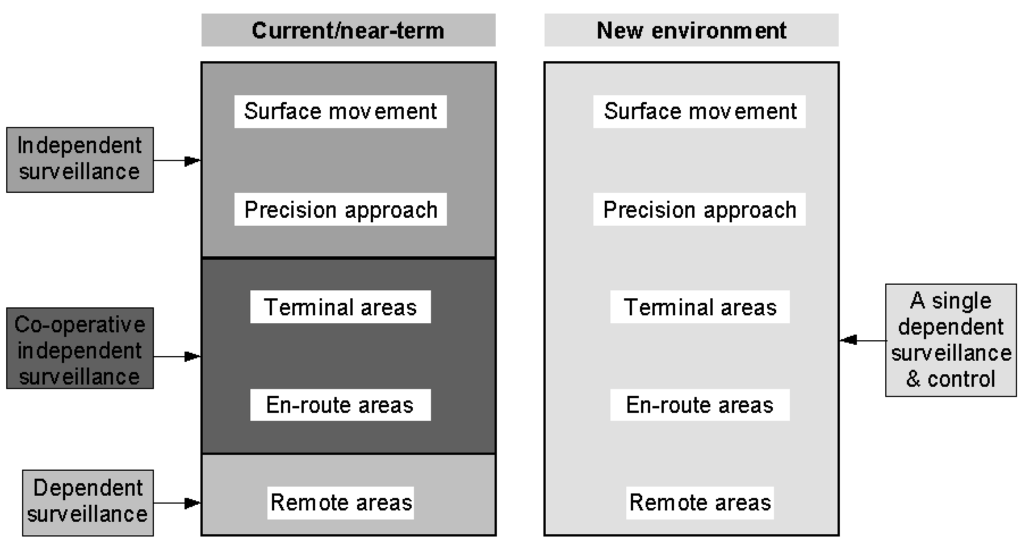


Figure E.2-7: New ATM Surveillance environment

E.2.1.1 Air-Air wrt TCAS

VDL Mode 4 ADS-B is designed to operate as an autonomous air-air surveillance system. With VDL Mode 4 ADS-B in operation, the TCAS collision avoidance system could be used as a back-up or last minute safety net in case of loss of separation.

E.2.1.2 Air-Ground wrt SSR

ADS-B supported by VDL Mode 4 is able to act as an alternative to SSR. However, with VDL Mode 4 in operation, SSR could be used as a back-up system for ATC surveillance.

E.2.1.3 Independent Validation of Position Reports.

The VDL Mode 4 will (when synchronised to primary timing) independent of any other source measure the arrival time of all received position reports and calculate a position uncertainty volume of the received position. If the received position is outside the calculated volume the received position will be treated as non-reliable.

The accuracy of arrival time measurement will be in the order of 1 μsec giving an uncertainty volume of approximately 1000 ft. or approx. 300 meters *(Ref. SARP 2.1.4.2)*

E.2.1.4 Failure Mode and Recovery

VDL Mode 4 is proposed to operate with two 25 kHz channels, so-called Global signalling Channels (GSCs). The system has built in graceful degradation modes as illustrated in Figure E.2-8. In case of loss of primary timing the system can operate by slaving on own internal accurate clock, other mobiles or ground stations timing source(s). The VDL Mode 4 system has by design integrity monitoring for fault detection/fault isolation of all used sensors (both own and aircraft sensors). This gives the system a robust and predictable Graceful Degradation mode.

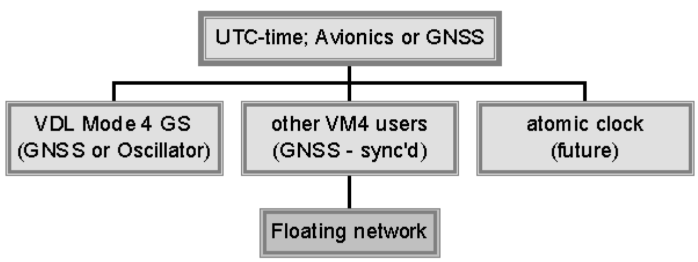


Figure E.2-8: Primary and Secondary Timing

E.2.2 Quality of Service

(see 'Performance and capacity of ADS-B using VDL Mode 4', G. Frisk, Swedish CAA)

ADS-B supported by VDL Mode 4 is able to meet MASPs requirements for quality of service (see Section E.1.3.1.2.3).

E.2.2.1 Availability/Continuity of Service

ADS-B supported by VDL Mode 4 will meet MASPs requirements for availability/continuity of service.

E.2.2.2 Integrity

E.2.2.2.1 Report Validation (interrogation/reply, TOA range estimate, etc.)

Time of arrival range estimates is inherent to the VDL Mode 4 system. A VDL Mode 4 station that is receiving messages from another station can deduce the distance of the transmitting station by the difference between the time of arrival of a message and the nominal start time of the slot in which it was transmitted.

E.2.2.3 Probability of Undetected Message Error

(See VDL Mode 4 SARPs 3.3.2)

A 16-bit cyclic redundancy check (CRC) is added to each message, as shown above in Table E.1-3. This reduces the probability of an undetected bit error in a message to 1 in 2^{16}.

Other integrity checks may further reduce the overall undetected message error rate.

E.2.3 Transition Approach

Where radar coverage already exists, VDL mode 4 ADS-B can be used as an 'overlay' to supplement performance and to provide air-to-air surveillance. In the long term, radar could be withdrawn, leaving just VDL mode 4 for air-to-air and air-to-ground and ground-ground surveillance. Primary Radar can provide the function of an independent safety net that may be required in high-density airspace.

E.2.3.1 Airborne Configuration

Alternative Airborne configurations for use of VDL Mode 4 as Stand-alone, Integrated equipment on Air Transport category aircraft and on GA are illustrated below.

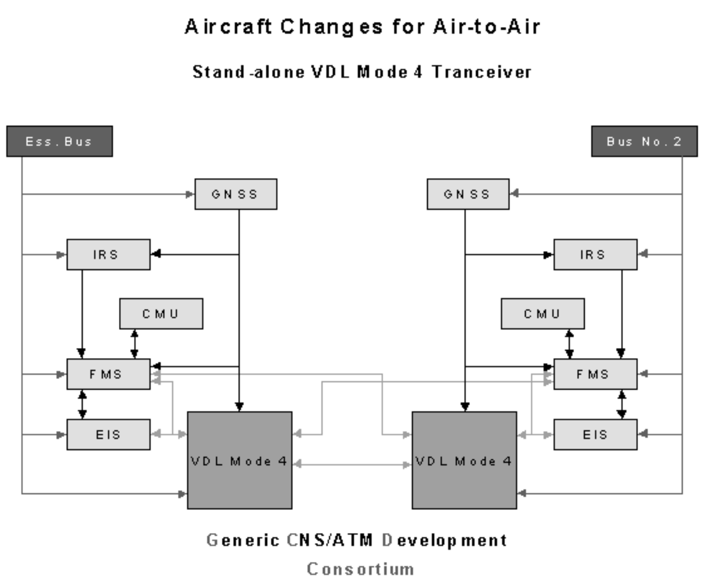


Figure E.2-9: Example of commercial aircraft architecture

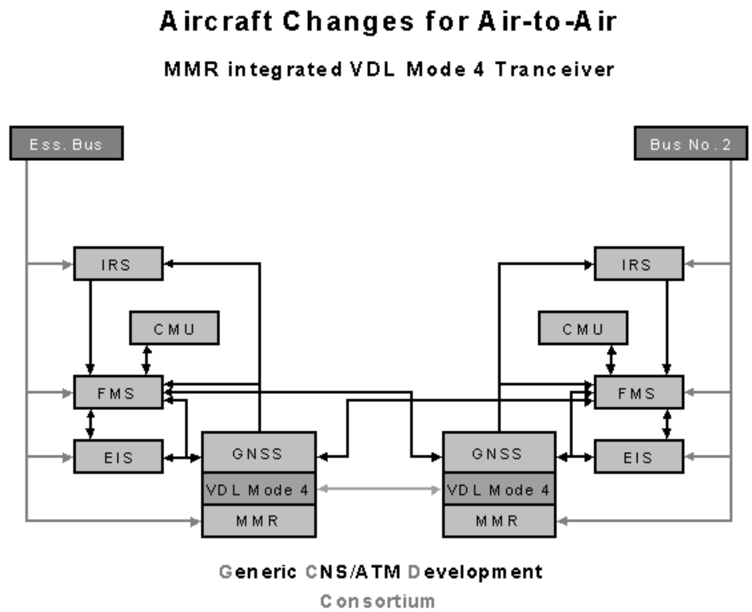


Figure E.2-10: Example of integrated aircraft architecture

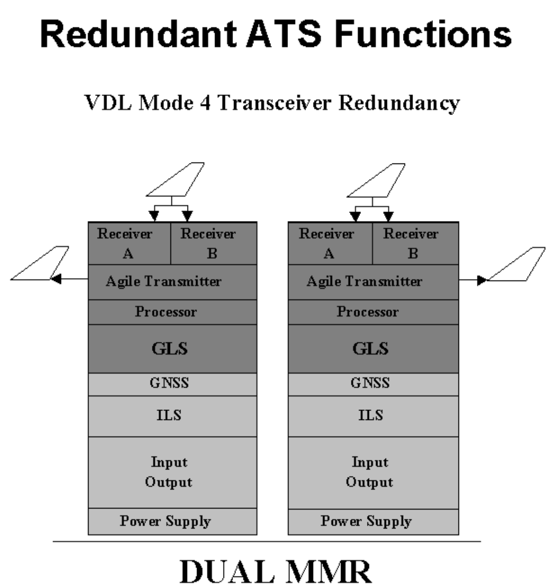


Figure E.2-11. Example of commercial aircraft MMR

Source: Airborne Architecture Group, February 1999.

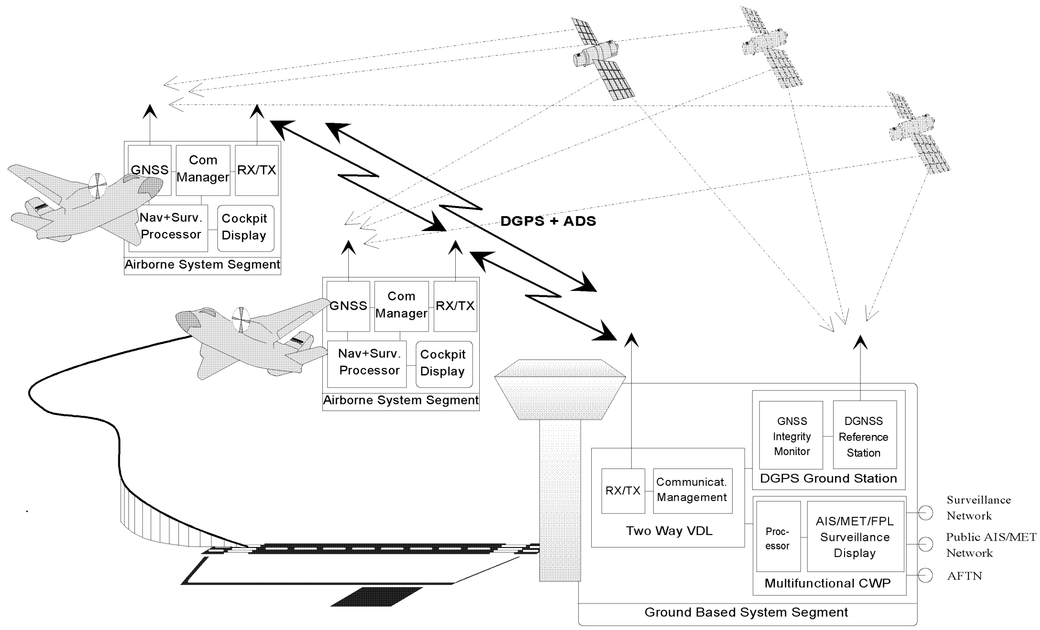


Figure E.2-12: Example of GA aircraft equipment used in the EC-sponsored project SUPRA

E.2.3.2 Ground ATC Configuration

The following Figure E.2-13 represents an example on how a future ATM Client-Server Network could be established. *Source: European Commission DG XIII ATLAS IIA Report.*

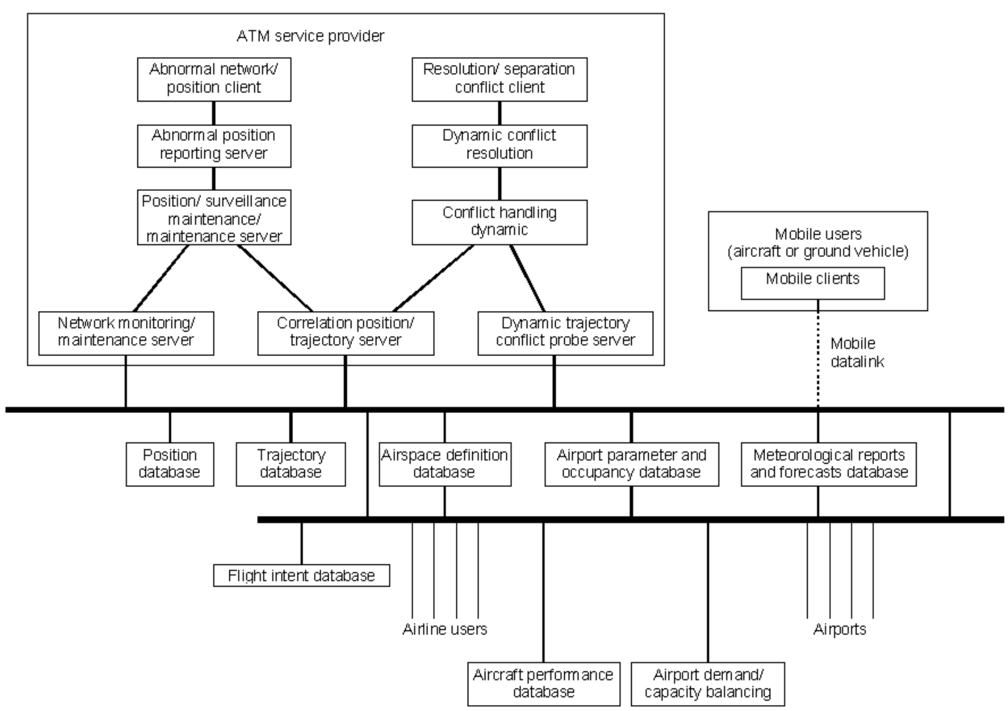


Figure E.2-13: Illustration of client-server ATM networks

E.3 Information Exchange Functionality

E.3.1 Broadcast Message Generation

E.3.1.1 Information Source Interface and Information Compression

The position information required to support VDL Mode 4 ADS-B position reports should be supplied by the aircraft navigation system(s) and avionics. The VDL Mode 4 ADS-B system requires a source of UTC time that could be supplied by the aircraft avionics or from a separate GNSS receiver.

Information compression should preferably not be used in VDL Mode 4 ADS-B. However, discussions are currently going on in ICAO/VSG on possibly using CPR encoding of Lat/Long.

E.3.1.2 Message Assembly, State Vector Extrapolation, and Broadcast

In general there is a near one-one correlation between messages and reports, so only simple message assembly is required. No state vector extrapolation is required in VDL Mode 4 ADS-B, as all position reports are time-stamped.

E.3.2 Message Reception and Output Reports

E.3.2.1 Message Reception and Information Decompression

Information decompression is not required in VDL Mode 4 ADS-B as information compression is not used. See also 3.1.1. above.

E.3.2.2 Report Assembly Flow Chart

E.3.2.2.1 Acquisition

A first position report gives an aircraft's position within a region of 600 x 600 nautical miles (which is significant larger than the VHF coverage). A second position report allows complete position resolution and removes ambiguity. Hence the acquisition time is the time taken to receive one report if a position report within 600 x 600 nm is required, or it is the time taken to receive two reports if the full unambiguous position is required.

E.3.2.2.2 Tracking

No tracking functions are required by the VDL Mode 4 ADS-B system. Such functions would be provided by associated applications.

E.3.2.2.3 Coast Suspend and Re-acquisition/Drop

Every VDL Mode 4 station will maintain a contact table of all known transmitting stations. A counter G1 is used to decide whether a peer station has become unreachable and should be deleted from the table. The counter G1 is set to zero when the first transmission from a peer station is received. It is decremented (but not below zero) when a transmission is received from the peer station, and incremented when a transmission, for which there is a prior reservation, was missed. If G1 reaches 4, equivalent to 4 missed transmissions; this peer station is deleted from the contact table. The number of missed transmissions is a configurable parameter.

E.3.3 Reports and Supported Applications

E.3.3.1 Output Report Format wrt MASPS Format

The output format from VDL Mode 4 equipment is an implementation issue.

E.3.3.2 Application Interface

E.3.3.3 User Adaptation Features

VDL Mode 4 possesses a large potential for user adaptation as it can support a two-way data link allowing any one user (Mobile or Ground) to request specific information from another.

E.4 Message Reception and Co-channel Interference

E.4.1 Interference Sources

Interference may occur from the standard VHF interference sources that are:

- other transmitters located on the same aircraft;
- other electronic equipment on the same aircraft;
- transmitters on nearby aircraft, or nearby ground stations which may be operating incorrectly, or correctly but still causing interference;
- various non-aviation sources such as FM broadcast transmitters, industrial sources, medical and scientific sources;

All existing prototype VDL Mode 4 systems used on aircraft (approximately 60 units on board different types of Commercial aircraft, Military aircraft, GA and Helicopters) have been certified in accordance with the EUROCAE ED-14/RTCA 160/JAA Form 1 requirements.

In VDL Mode 4, stations may use slots previously reserved by other stations that are at a considerable distance away. In order to ensure that the use of previously reserved slots does not cause interference to transmissions, special rules for their use have been adopted.

The special rules for the re-use of previously reserved slots are based on two guiding principles:

1. Robin Hood;

2. Co-channel interference (CCI) protection.

The Robin Hood principle allows a station operating on a busy channel to use slots previously reserved for broadcast transmission by another station as long as slots reserved by the most distant stations are chosen in preference to those of nearer stations. This results in a graceful reduction in the broadcast range of a station on busy channels as illustrated in Figure E.4-1.

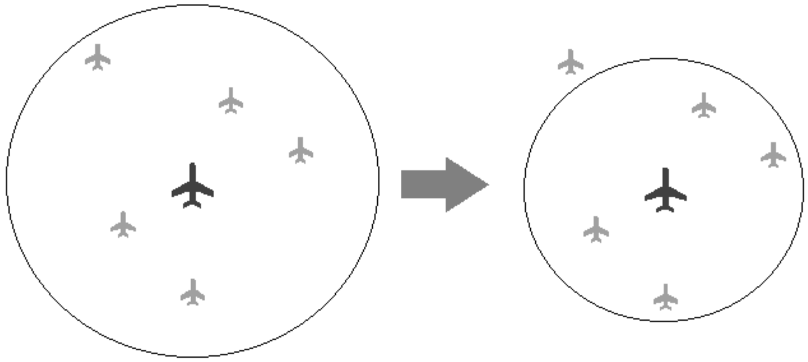


Figure E.4-1: Graceful cell shrinkage resulting from use of the Robin Hood principle

CCI protection generalises the Robin Hood principle to allow slots previously reserved for point-to-point communication between two stations to be used by another station. CCI protection is based on relative aircraft distance and assumes that even though stations may be in radio range of each other, each station can successfully discriminate the desired (stronger) signals over the undesired (weaker) ones. VDL Mode 4 defines a measure of the co-channel interference (CCI) on the basis of free space attenuation of signals with distance. For GFSK modulation, discrimination can occur as long as interfering signals are different by 10dB, equivalent to a range ratio between interfering sites of approximately 3.

Figure E.4-2 illustrates how CCI protection operates.

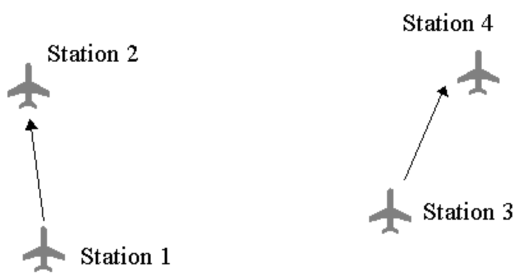


Figure E.4-2: CCI protection

Station 1 wishes to communicate with Station 2 but is unable to find a suitable free slot. Station 3 has reserved a slot to communicate with Station 4. Since Stations 3 and 4 are more distant stations, Station 1 considers using the same slot but must first check that the following conditions hold:

1. The transmission by Station 1 must not prevent Station 4 being able to decode the transmission from Station 3. Hence, applying the CCI criteria, the range from Station 1 to Station 4 must be greater than three times the range from Station 3 to Station 4.

2. Station 2 must be able to decode the transmission from Station 1 without being prevented by the transmission from Station 3. Hence, applying the CCI criteria, the range from Station 2 to Station 3 must be greater than three times the range from Station 2 to Station 1.

If both these criteria are met, then Station 1 can use the slot.

E.4.1.1 TDMA Slot Overlap

In VDL Mode 4 ADS-B, a Guard Time is built into the end of each message to give the transmitter signal time to decay and to protect against TDMA slot overlap caused by variations in transmitter-receiver distances. During the Guard Time, the transmitter signal decays in the first 300 microseconds, and then there is no transmission for the next 950 microseconds (longer for D8PSK modulation) until the end of the slot. The total guard time length of 1250 microseconds is equivalent to a 205 nautical mile guard range.

E.4.1.2 Random Access Interference

Random access interference is greatly reduced due to the use of a number of different reservation protocols. The VDL Mode 4 ADS-B system uses standard non-adaptive p-persistent algorithm to equitably allow all stations the opportunity to transmit while maximising system throughput, minimising transit delays, and minimising collisions.

E.4.1.3 Multipath (Air-Air and Air-Ground)

Multipath has the effect of increasing the BER. No significant impact of multipath has been observed during prototype VDL Mode 4 equipment trials during 9 years.

E.4.1.4 Ownship Suppression Effects on Link Availability

While transmitting, a VDL Mode 4 station may suppress its receive capability on other VDL Mode 4 channels. This means that the station may miss one or more slots on another channel(s). While transmitting at a nominal rate of once per 20s on each GSC, this might result in 6 missed slots per minute (of the total 4500).

With some implementations, and depending on the channel separation, the station may be able to receive while simultaneously transmitting.

E.4.2 Decoder Response

E.4.2.1 Synchronization Detection and False Synchronization Lockout Time

The synchronisation sequence is described in Section E.1.2.3.

There is no false synchronisation lock-out time. A station synchronises at the start of each received burst. If the synchronisation of a burst fails, then it will not be received correctly.

E.4.2.2 Probability Correct Decode with SIR and SNR as Parameters

(See VDL Mode 4 SARPs Section 2.6)

A station is capable of decoding a GFSK transmission in the presence of an interfering transmission as long as the Co-Channel Interference (CCI) is greater than 12dB.

E.4.2.3 Multipath Susceptibility

Multipath has been discussed in Section E.4.1.3.

E.5 Subsystem Block Diagrams

A VDL Mode 4 equipment manufacturer can provide information missing in this section. For proposed end state airborne architecture see Figures E.2-9 through E.2-12.

E.5.1 Proposed Equipage Classes

In the following tables, three levels of equipage are described. These range from the most demanding equipage for Air Transport (level α) down to General Aviation (level γ).

Table E.5-1: Level α equipage

Users	Air Transport/very sophisticated GA
ADS-B services	ADS-B message broadcasting, FIS-B, TIS-B
Operation	In airspace where ADS-B is mandatory requirement and operator has low tolerance of disruption to mission due to equipment failure.
Channel usage	ADS-B reporting on 2 GSCs and also, at times and under direction of a ground station, on one LSC.
VDL 4 transceiver	Two units with 1Tx and 3-4Rx
Redundancy	Multiple redundant transceivers, with cross-links allowing system wide re-configuration in event of component failure.
Certification	Software certification level DO-178C, level B

Table E.5-2: Level β equipage

Users	Not quite such sophisticated GA
ADS-B services	ADS-B message broadcasting, FIS-B and TIS- B
Operation	More diverse than level α. Requires access to airspace where ADS-B is mandatory, but prepared to disrupt mission in event of equipment failure.
Channel usage	ADS-B reporting on 2 GSCs and also, at some times and under direction of a ground station, on one LSC
VDL 4 transceiver	One transmitter and three receivers.
Redundancy	Single VDL 4 transceiver.
Certification	Software certification level DO-178C, level C

Table E.5-3: Level γ equipage

Users	Low end GA
ADS-B services	ADS-B message broadcasting, FIS-B and TIS-B
Operation	Predominantly VFR with possible IFR outside airspace where mandatory carriage requirement exists.
Channel usage	ADS-B reporting nominally only on the 2 GSCs.
VDL 4 transceiver	One transmitter and three receivers
Redundancy	Single VDL 4 transceiver.
Certification	Software certification level DO-178C, level C

Source: EUROCAE WG-51 Working Documents.

E.5.2 Relationship of Each Class to Evaluation Units

Prototype units used by Swedish CAA for the ICAO validation work has software certifiable to DO-178 C, level C and which subsequently can be upgraded to level B. For equipment used in SF 21 trials PMEI/ADSI and UPS Aviation Technology can provide information.

E.6 Miscellaneous

E.6.1 TIS/TIS-B Description (as Appropriate Area-Wide Uplink Channel Rate)

VDL Mode 4 supports TIS-B using uplink broadcasts from ground stations. These transmissions are made in ‘protected slots’ so that airborne ADS-B transmissions do not overlap with the uplink broadcasts. TIS-B may be transmitted on the same or different channels as ADS-B. A Draft specification under testing in Europe is attached as Appendix E-B.

E.6.2 FIS/FIS-B Description (as Appropriate Area-Wide Uplink Channel Rate)

Like TIS-B, VDL Mode 4 supports FIS-B using uplink broadcasts from ground stations. FIS-B broadcasts may include ATIS and weather information uplinks. FIS-B is an advisory service only.

E.6.3 GNSS Augmentation

VDL Mode 4 Ground Stations are providing GNSS Augmentation throughout the NEAN, NAAN networks and by other Ground Stations not yet included in these networks. Although ICAO has not yet accepted it, the GNSS Augmentation capability is intended to be included in the EUROCAE MOPS and other relevant European Standards. GRAS has been included in the GNSSP working program at GNSSP/3 held in April 1999.

E.7 Growth Potential or Other Features Not Treated Above

VDL Mode 4 has the capability to support functions other than ADS-B. Other applications that can be supported include:

- Air-to-air applications, such as trajectory exchange; (Demonstrated in FREER 3.).
- Uplink broadcast applications, e.g. TIS-B; (Demonstrated in the FARAWAY project).
- CPDLC (demonstrated in the PETAL II-project).
- ATN communications;
- Specific services (non-ATN) communications.
- Voice Communications
- AOC

E.8 Summary of System Characteristics

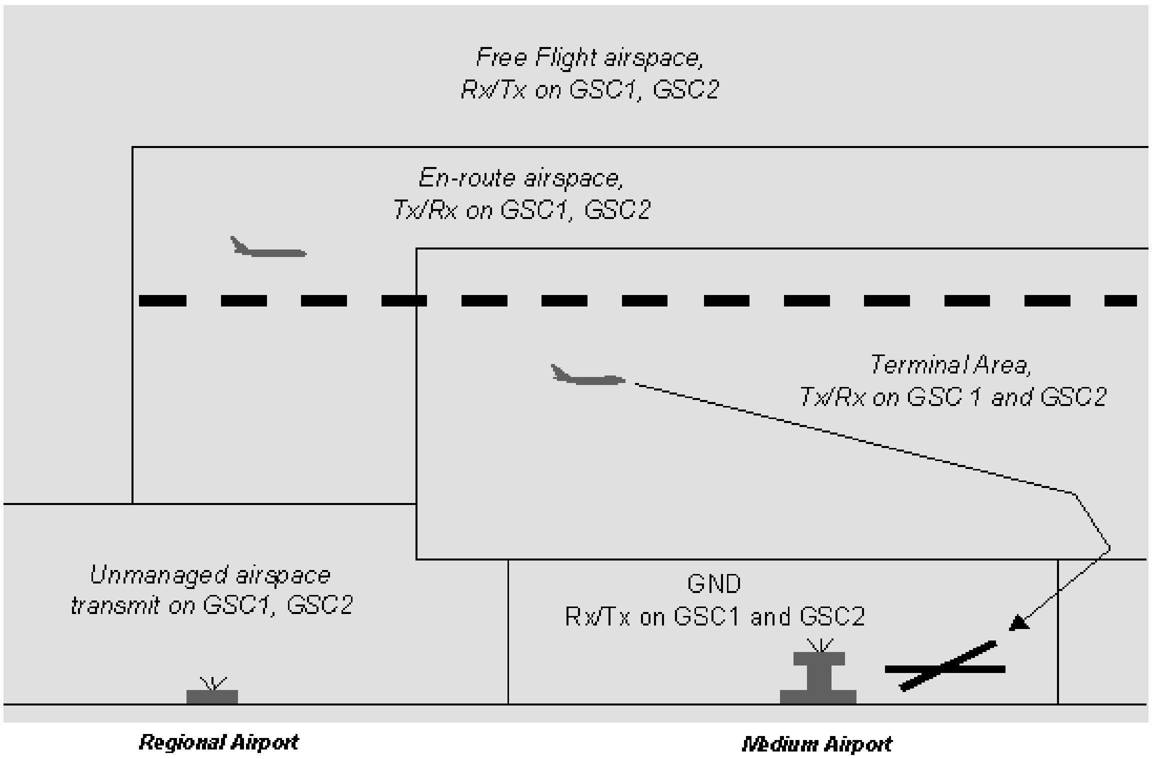
	Operational System	**Test System in US 1999** (Presented by ADSI)
Frequency band	108,0 - 136,975 MHz	Same
Range	More than 200 nm	Same
Bandwidth	25 kHz per channel.	Same
Bit rate	19,200 bits/sec	Same

Modulation	Binary GFSK/FM; MI 0,25 ± 0,03; BT product 0,28 ± 0,03; 19,2 kbps ± 50 ppm *(SARP para. 2.3.2)*	Same
Channel selection time	<10 ms *(SARP para. 2.1.1)*	Similar
Transmitter power stabilisation (90% of steady state power level)	<832 µs *(SARP para. 2.3.3.1)*	Same
Synchronisation and ambiguity resolution	24 bit binary sequence (0101 0101 0101 0101 0101 0101) *(SARP para. 2.3.3.2)*	Same (pre-NRZI)
Maximum Usable Sensitivity	-103dBm at BER 10^{-4}	Per JHU/APL tests
Receiver to transmitter turnaround time	< 1 ms *(SARP para. 2.5.1)*	Same
Transmitter to receiver turnaround time	< 1 ms *(SARP para. 2.5.3)*	Same
Primary time synchronisation to UTC	< 2σ value of 400 ns *(SARP para. 3.2.3.1)*	Same (assumes valid pps)
Secondary time synchronisation	< 2σ value of 5000 ns and announce secondary time synchronisation *(SARP para. 3.2.3.2)*	Same (meets end system spec.)
Frequency capture range	Signals with a frequency offset from nominal of ±965 Hz *(Ref. VDL Mode 2)*	Same
Preamble	First 24 bits (0,832 ms)	Same
Slot Length	4,500 x 256 bits/minute/ channel	? -256 bits (13,3 msec.)
Parity	16 bits	Same
Address	24 bits + 3 bits (27 bits)	Same
Longitude/Latitude	14 bits even/12 bits odd (Modified CPR encoding/ decoding)	Same, (will meet end system spec. CPR as spec'd in SARPs
PVT Segmentation	Together in the same message	Same
Transmitter power (at antenna)	High-end 44 dBm +-3dB Medium 40 dBm +-3dB Low-end 37 dBm +-3dB	1 to 25 W variable, runtime configurable
Receiver sensitivity (MTL?)	- 103 dBm at BER 10 - 4	Per JHU/APL tests
Polarisation	Vertical	As installed (vertical)
Transmission rate, PVT	1, 2, 5 or 10 seconds (can be varied between 1-60; event driven or by command)	1,2,3,4,5,6, 7.5,10,12,15,20,30 or 60 per channel per application
Multiple Access Technique	Self-organising TDMA (Slots 2x 75 slots/sec.)	Same
Channels	2 x 25 kHz Global Signalling Channels (ADS-B) + Local channels for additional services as required	Same
Guard Channels	None (ICAO and ETSI mask compliant)	Same (AMCP/WG-B will specify spectrum engineering criteria)
Flexibility and growth potential	Organised link, that handles all types of data link messages incl. Time-critical message exchange; growth through Directory of Service message from GND station plus additional local 25 kHz channels	Test system configured to support known evaluation and validation requirements

Channel Loading

Scenario: Low Density

300 aircraft within 400 nm radius.



Minimum number of Tx/Rx : 1 Tx + 2 Rx.

Transmit: ADS-B = every 10 sec. en-route; 5 sec. in TMA and 1 sec. on GND.

Receive: TIS-B, FIS-B (240 slots/min), DoS plus GRAS (120 slots/min)

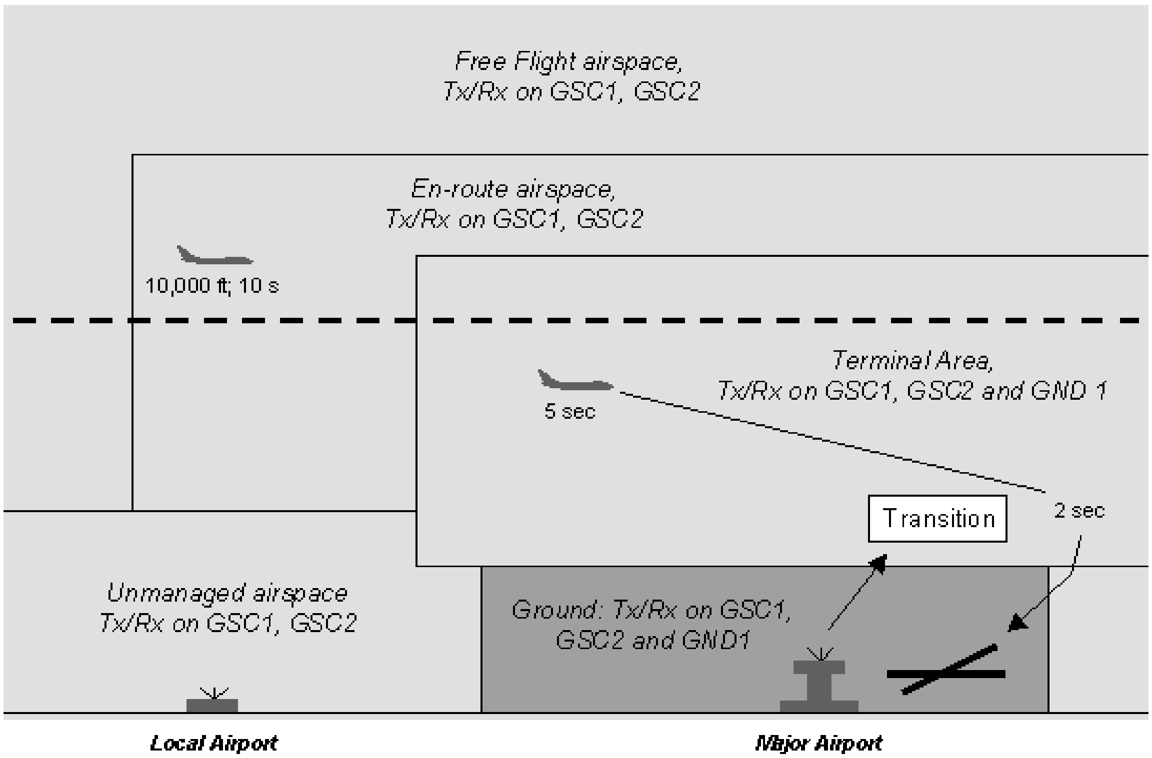
Remaining capacity for ADS-B/TIS-B = 1400 airborne and ground vehicles with 10 sec. update rate, 700 units with a 5 sec. update rate and 140 units with 1 sec. update rate.

Assume: 40 GND units 1 sec.(10%); 100 aircraft in TMA 5 sec. (30%) and 160 aircraft en-route 10 sec.: Link load ~55 per cent.

Note. Robin Hood effect not assumed.

Scenario: Future High Density

Core Europe - 1356 aircraft within 400 nm radius plus GND traffic.
LA Basin,US - 1700 aircraft within 400 nm radius plus GND traffic.



Minimum number of Tx/Rx: 1 Tx + 3 Rx

Transmit: ADS-B every 10 sec. in FFAS, En-route and in TMA above 10,000 ft; 5 sec below 10,000 ft, 2 sec., during Approach, GND 1 sec., GA with lower speed than 140 kt every 10 sec., military every 5 sec.

Receive: TIS-B, FIS-B (240 slots/min), DoS plus GRAS (120 slots/min) on GSC1, 2 and GND1.

Note: During a transition period the capacity is higher since TIS-B messages (sent in blocks of 2 slots each containing 5 a/c or vehicles) requires less bits than a full ADS-B report.

Potential effects of the slot reuse scheme (Robin Hood) is not calculated.

Further details are presented in Appendix E-A and E-B to this document.

ADS-B Report Implementation Over VDL Mode 4

Introduction

The VDL Mode 4 system is in the basic configuration operating with two 25 kHz GSCs containing 2x 4,500 time-slots per UTC minute. Additional capacity is made available by adding receivers. Current hardware includes 1 Rx and 4 Tx. Each slot comprises 256 bits of data or 32 octets. 8 octets (64 bits) are used for power ramp up, synchronisation, transmitter shut down and guard time. The 24 octets (192 bits) of data is used for; 2 octets (16 bits) flag and 1 octet (8 bits) for but stuffing which leaves 21 octets or 168 bits for data. Of the 21 octets 32 bits (4 octets) are used for; source address 27 bits (including the 24-bit ICAO address), 3 bits for version no., 1 bit for reservation ID and 1 bit to indicate if it is a burst or a frame transmission). 2 octets or 16 bits are used for CRC and 10 bits for reservation data. The remaining 110 bits are subdivided into a fixed and a variable portion with 56 bits in the fixed part and 54 in the variable part.

Fixed Part

Information field	No of bits	Comment
Message ID field	2	In general this is a variable part. For a synchronisation burst the lst bit is always set to 0. The other bit (autonomous/directed mode flag) is used to denote a autonomous or directed burst.
TFOM	2	3 timing states defined (primary, secondary and tertiary).
NUCp	4	Provides for the definition of 16 possible states.
CPR Odd/even identifier	1	Denotes whether the position info (CPR encoding) is the odd or the even part.
Latitude	12	The 12-bit CPR encoding provides position to a resolution of approximately ±140 m, within a segment (patch) of approximately 600 nmi. Note that an unambiguous position is normally obtained when two reports have been received (see Section E.3.1.4).
Longitude	14	The 14-bit CPR encoding provides position to a resolution of approximately ±120 m, within a segment (patch) of approximately 600 nmi. Note that an unambiguous position is normally obtained when two reports have been received (see Section E.3.1.4).
Baro/geo altitude identifier	1	Denotes whether baro or geo altitude is transmitted. By default it will be 0 (barometric altitude if available).
Altitude	12	If b/g = 0 then barometric altitude is reported using the format specified in DO-181A, Otherwise geometric altitude is reported using a specific format specified in the SARPS.
Data age (Latency)	4	Describes the age of the transmitted data encoded as described in the SARPs.
Variable part ID	4	It identifies the information contained in the variable part within the sync burst
	56	

Variable part

Information on the content in the variable part of the ADS-B messages as defined by ICAO/AMCP VDL Mode4/VSG is provided in the following table.

Information field	No of Bits	Encoding	Notes
NUCr	3	Values 0, 1, 2, 3, 4 in accordance with the five NUCr categories specified for ADS-B MASPS by RTCA/DO-242	Provides for the definition of 8 possible states
Latitude	4/6/8	A high-resolution component to enhance the 12-bit low-resolution encoding transmitted in the fixed part	Different possibilities for different variable parts
Longitude	4/6/8	A high-resolution component to enhance the 14-bit low-resolution encoding transmitted in the fixed part	Different possibilities for different variable parts
Altitude offset	7	Barometric - geometric altitude Specific encoding defined in SARPs	
Altitude rate flag	1	0 = barometric altitude rate 1 = geometric altitude rate	
Altitude rate	9/11	Linear encoding with a step of 100fpm	1 bit is used as climb/descend flag (sign) and the other are used to provide a range of ±102150 fpm for the 11 bit case
Ground speed	11/13	Specific encoding is specified in the SARPS	0 to 3070 knots for 11 bits and to 27640 for 13 bits. Variable step from 1 knot to 4 knots.
Ground track	11	0 = due North, Resolution is 360/2048 = 0.1757 degrees, linear	0° to 359.824° Note.- ground track Is the same as true track
Turn indication	2	0 = left, 1 = right, 2 = straight, 3 = unknown	
Patch ID	10	Encoding is described in SARPs	
UTC year	8	current year - 1970, 0= N/A	1-255
UTC month	4	Linear	
UTC day	5	linear 00= N/A	
UTC hours	5	Linear	
UTC minute	6	Linear	
UTC second	6	Linear	
Slot	8 ?9?	linear - 0 indicates the first slot in the second frame	0 to 255
Trajectory point/leg type	4	As per Mode S A.4.9.1	0-15
TCP data valid	1	0 = invalid 1 = valid	
TCP type	1	0 = current 1 = next	
TCP time to go	6	As per Mode S A.4.9.5	
Call sign	42	Encoding for call sign: Call sign shall be left justified Only valid characters are A-Z, 0 - 9 and null: Assign A- Z = 0 - 25, 0 - 9 = 26 - 35, null = 36 Call sign shall be an eight character string "$c_1, c_2, c_3, c_4, c_5, c_6, c_7, c_8$" $Csl = c_1\ 36^3 + c_2\ 36^2 + c_3\ 36 + c_4$ $Csr = c_5\ 36^3 + c_6\ 36^2 + c_7\ 36 + c_8$	
A/c category	5		24 categories are specified in the MASPS
A/c status	3		8 categories are specified in the MASPS
?Air Speed			
?Report mode	2		3 possibilities (acquisition, track, default)???
?velocity (north, east), vertical rate			

Attachment E3

Some Successfully Completed and On-Going Projects

Trial	Sponsored by	Applications tested	Service provider participants include	Industry participants include
NEAN NEAP (successfully completed- Two 1997 Aerospace Industry Awards)	European Commission	ADS-B DGNSS uplink SMGCS TIS-B (planned)	German CAA (DFS) Danish CAA (SLV) Swedish CAA (LFV)	Deutsche Lufthansa SAS (Scandinavian Airlines) Maersk Air OLT, Germany Golden Air, Sweden SAAB-Celsius Transponder Tech, Sweden
FARAWAY (successfully completed - Finalist for 1998 Aerospace Industry Award)	European Commission	ADS-B TIS-B DGNSS uplink	Italian CAA (ENAV) Swedish CAA (LFV)	Alitalia, Italy ITALATC, Italy Iberia, Spain SAS (Scandinavian Airlines) Alenia, Italy Daimler-Benz Aerospace, Germany (DASA) GP&C Global Support, Denmark
FARAWAY II	European Commission	ADS-B TIS-B DGNSS uplink ADS-Contract Multiple ATC Center installations	Italian CAA (ENAV) Swedish CAA (LFV)	Alitalia, Italy Air Valle, Italy Alenia Marconi, Italy/UK ITALATC, Italy EuroTelematics GmbH, Germany SAAB-Celsius Transponder Tech Indra, Spain Alcatel ISR/Thomson, France
SUPRA (successfully completed - 1998 Aero-space Industry Award)	European Commission	ADS-B/CDTI GNSS Augmentation ATIS uplink For GA aircraft	Spanish CAA (AENA)	Indra, Spain Spanish Flying School Alcatel ISR, France Daimler-Benz Aerospace, Germany
PETAL II FREER	Eurocontrol	CPDLC Air-to-air and air-ground end-to-end com	Swedish CAA (LFV)	Lufthansa, Germany SAS Scandinavian Airlines Maersk Air, Denmark SAAB-Celsius Transponder Tech, Sweden
NAAN	European Commission	ADS-B DGNSS uplink	Danish CAA (SLV) Norwegian CAA Icelandic CAA	SAS (Scandinavian Airlines) Iceland Air, Iceland SAAB-Celsius Transponder Tech, Sweden
MAGNET-B	European Commission	ADS-B DGNSS uplink SMGCS	Swedish CAA	NLR, Holland Daimler-Benz Aerospace, Germany Dassault Electronique, France
DEFAMM	European Commission	ADS-B A-SMGCS	Aeroport de Paris DFS, Germany Flughafen Köln/Bonn	Alcatel ANS and IRS Alenia S.p.a. DASA Dassault Electronique S.A. DLR, Germany National Avionics, Ireland NLR, The Netherlands Oerlikon-Contraves S.p.a. Instituto Nacional de Technica Aerospacial
North European Update Programme (NUP)	European Commission	ADS-B DGNSS Augm A-SMGCS TIS-B Station keeping, etc.	German CAA (DFS) Danish CAA (SLV) Swedish CAA (LFV) France DGCA	Airbus Industries Deutsche Lufthansa SAS (Scandinavian Airlines) Maersk Air OLT, Germany Golden Air, Sweden SAAB-Celsius Transponder Tech, Sweden. Sofreavia, France.

Attachment E4

Selected References

[1] The Swedish Development of GPS/GLONASS User Systems, ICAO 10TH AN Conf./WP/30, September 1991.

[2] GNSS-based CNS/ATM - Information Papers on Development Status, ICAO/FANS II/1-2, Swedish CAA.

[3] Differential GPS at Chicago and Dallas Forth Worth airports, ICAO/FANS II/3 WP 32, ARINC.

[4] A Cost effective Solution to the Implementation of a World-wide civil Aviation GNSS Based ATN and Data Link System concept, ICAO/FANS II/3 WP 56,

[5] Consideration of Global Standards for ADS in the Terminal Area and at Airports, ICAO/FANS II/3 WP 61, IATA

[6] A Cost effective World-wide GNSS based Cellular CNS/ATM Systems Concept, ICAO/FANS II/4 WP 21, Swedish CAA.

[7] Summary of Statements and Recommendations related to GNSS-based CNS/ATM, ATC and ATN data link issues, and some Technical Details and System Operations of a Prototype System Concept. ICAO/FANS II/4 WP 46, Swedish CAA.

[8] Capacity and Safety Considerations of Alternative VDLs, ICAO/AMCP/3 WP 23, Swedish CAA.

[9] Hybrid GNSS/ILS System , ICAO/AWOP WP 46, Swedish CAA.

[10] The Need for Surveillance Beyond ADS, ICAO ADSP/3, IATA WP.

[11] "APPENDIX R - The GNSS Transponder - A Cost Effective World-wide GNSS-based Civil Aviation, DGNSS, CNS/ATM, ATC, ATN Data Link and Collision Avoidance System Concept". RTCA Task Force 2, Washington D.C., October 1993, Swedish CAA. (NOT PUBLISHED).

[12] A GNSS-Based Time Division Multiple Access Data Link, J. Nilsson and H. Lans, Air Traffic Control Quarterly, USA, 1994;

[13] Evaluation of the Swedish GP&C System for ASTA Data Link, US DOT/VOLPE Centre, Report, October 1994

[14] GNSS Landing Trials and ILS GP/GNSS LLZ Hybrid System, CARD-Project/Swedish CAA Report, January 1995

[15] An Alternative Architecture that may Facilitate the Transition from ILS to GNSS, A Hybrid ILS/GP - GPS Architecture. ICAO Special COM/OPS/95, Agenda Item 3, Swedish CAA WP 32, March 1995.

[16] Draft VDL/TDMA SARPs for the Application and use of STDMA for VHF Air - Ground Communications, ICAO/AMCP WG-D/3, WP-8, Martinique, May 1995.

[17] CCC -Discrimination of Weaker Signals Using STDMA VHF/GMSK, ICAO/AMCP WG-D/4, WP, Montreal, November 1995.

[18] VDL Mode 4 Standards and Recommended Practices (SARPs), Draft version 6.0 and Detailed Technical Manual version 5.4.6.; ICAO AMCP Validation Sub-Group (VSG), 12/10/99.

[19] Evaluation of STDMA for Use on the Airport Surface, Phase II Test Report, FAA, October 6, 1997.

[20] NUP Project outline, Swedish CAA, December 1998.

[21] North European ADS-B Network (NEAN): Final Project Summary and Conclusion Report, NEAN project group, February 1999.

[22] NEAP GNSS Precision Navigation Capability for En-route and Approach, Evaluation and Equipment Performance Report, Gunnar Frisk, Swedish CAA, 19 Mars 1999.

[23] Development of appropriate recommendations on the required navigation performance (RNP) for approach, landing and departure operations, ICAO AWOP/16 WP/756, Report on Agenda Item 1, 28/06/97.

[24] Evaluation Methodology and Test Reporting For New Approaches And Landing Systems, ICAO AWOP/16 WP/756, Report on Agenda Item 3, Appendix B, 03/07/97.

[25] Aeronautical telecommunications, Annex 10, ICAO.
[26] Minimum Operational Performance Specification for VDL Mode 4 Aircraft Transceiver, DRAFT, EUROCAE WG-51, SG-2.
[27] Radio Equipment and Systems (RES): Study of feasibility for standardizing Self-Organized Time Division Multiple Access (STDMA) system requirements, ETSI, November 1997.
[28] RTCM Recommended Standards for Differential NAVSTAR GPS Service, RTCM SC-104, Version 2.1, 03/01/94.
[29] FARAWAY Project Report, European Commission, August 1998.
[30] SUPRA Project Report, European Commission, September 1997.
[31] GNSS Landing Trials at Kungsangen Airport, Swedish CAA, Version 1, 21/04/95.
[32] Distributed Integrity Monitoring of Differential GPS Corrections, Master Thesis final report, Linkoping University, Martin Pettersson, Swedish CAA, 21/12/98.
[33] VDL Mode 4 Flight Test Report, Swedish CAA, August 1999.
[34] Minimum Aviation System Performance Standard for Automatic Dependent Surveillance Broadcast (ADS-B), RTCA/DO-242, 19/02/98.
[35] Test Plan for GNSS Precision Navigation Capability for En-route and Approach, Per Ahl, SAS, Gunnar Frisk, Swedish CAA, Version 1.0, 30 January 1999.
[36] F28 Pilots Training Document for NEAP Instrument Approach with Vertical Guidance at Angelholm Airport, B Moberg, P. Ahl, A. Akerberg, SAS, Version1.2, 12/11/98.
[37] Ground-basedRegional Augmentation System (GRAS), Swedish CAA, Working Paper to GNSSP in Montreal 12 - 23 April 1999.
[38] Ground-based Regional Augmentation System (GRAS), Development in Northern Europe - Status report, Swedish CAA, Working Paper at GNSSP in Montreal 12 - 23 April 1999.
[39] Surveillance tests with GNSS and STDMA data link at Amsterdam Airport Schiphol, C.G Kranenburg, T.J.J. Bos and A.J.C. de Reus, NLR, the Netherlands, August 1999.

Attachment E5

Link Management

This attachment comprises detailed information on the format of the synchronisation burst. The information in the synchronisation burst is used for management of the VDL Mode 4 link as well as by ADS-B and other applications. Only information related to the link management function is addressed. References to the draft Manual on Detailed Technical Specifications for the VDL Mode 4 Data Link are given.

The Directory of Services (DoS) message format is under final review by the AMCP VSG at this time, and will be included in this appendix later.

E5.1 Sync Burst

(Manual on Detailed Technical Specifications A.3.2)

The link management entity (LME) in VDL Mode 4 uses a sync burst to control the communications. A sync burst can also contain ADS-B related data.

The sync burst is divided into a fixed part, containing information required for communications maintenance as well as basic ADS-B information, and a variable part containing additional information used by the applications, e.g. ADS-B.

The complete sync burst is made up of the general burst header (Section E5.2), the fixed part of the sync burst (Section E5.3), and one of a number of possible variable sync burst parts (Section E5.4).

E5.2 General Burst Header

(Manual on Detailed Technical Specifications A.3.2)

The general burst header contains information on:

- the reservation type (VDL Mode 4 specific info - ground controlled or autonomous);
- the version number (to support growth);
- the source address (ICAO 27 bit address).

The rest of the burst is filled in according to the type of burst being transmitted.

Table E5-1: Burst format

Description	**Octet**	**Bit number**							
		8	7	6	5	4	3	2	1
flag	-	0	1	1	1	1	1	1	0
reservation ID (rid), version number (ver)	1	s_{27}	s_{26}	s_{25}	ver_3	ver_2	ver_1	rid	1
source address (s)	2	s_{24}	s_{23}	s_{22}	s_{21}	s_{20}	s_{19}	s_{18}	s_{17}
	3	s_{16}	s_{15}	s_{14}	s_{13}	s_{12}	s_{11}	s_{10}	s_9
	4	s_8	s_7	s_6	s_5	s_4	s_3	s_2	s_1
message ID (mi)	5	in_k	mi_k	. . . . . .		mi_4	mi_3	mi_2	mi_1
information	6								
	6 - n-5			. . . .					
	n-4								
reservation data (rd)	n-3		in_1	rd_k	. . . . . .				
extended reservation ID (erid)	n-2	$erid_k$	. . . . . .			$erid_1$			rd_1
CRC (c)	n-1	c_{16}	c_{15}	c_{14}	c_{13}	c_{12}	c_{11}	c_{10}	c_9
	n	c_8	c_7	c_6	c_5	c_4	c_3	c_2	c_1
flag	-	0	1	1	1	1	1	1	0

	. . . .		Denotes variable length field

E5.3 Fixed Data Field

(Manual on Detailed Technical Specifications A.5.2.2)

Fixed field information is always transmitted. The fixed data field contains information on:

- autonomous/directed flag;
- altitude type (baro/geo);
- CPR format;
- position uncertainty;
- latitude and longitude (accuracy for en-route phase);
- base altitude;
- time figure of merit;
- data age or latency.

The remaining part of the burst is set aside for one of the possible variable information fields (see Section E5.4 and Attachment E6).

The contents of the various data fields are detailed in Tables E5-2 and E5-3.

Table E5-2: Fixed Part of the synchronisation burst

Information field	No of bits	Comment
Burst	1	"0" indicates that the slot contains a synchronisation burst.
Autonomous/Directed mode	1	The bit is used to denote an autonomous or directed burst.
TFOM	2	3 timing states defined (primary, secondary and tertiary).
NUCp	4	Provides for the definition of 16 possible states.
CPR Odd/even identifier	1	Denotes whether the position info (CPR encoding) is the odd or the even part.
Latitude	12	The 12-bit CPR encoding provides position to a resolution of approximately ±140 m, within a segment (patch) of approximately 600 NM.
Longitude	14	The 14-bit CPR encoding provides position to a resolution of approximately ±120 m, within a segment (patch) of approximately 600 NM.
Baro/geo altitude identifier	1	Denotes whether baro or geo altitude is transmitted. As default, barometric altitude is sent if available ("0").
Altitude	12	If baro/geo identifier = "0", then barometric altitude is reported using the format specified in DO-181A, otherwise geometric altitude is reported using a specific format specified in the SARPs *(Manual on Detailed Technical Specifications Table A-65)*.
Data age (latency)	4	Describes the age of the transmitted data encoded as described in the SARPs *(Manual on Detailed Technical Specifications Table A-66)*.
Variable part ID	4	Identifies the information contained in the variable part within the synchronisation burst. If needed, additional eight bits for the ID are available in the variable part.
	56	

Table E5-3: Synchronisation burst format

Description	Octet	Bit number							
		8	7	6	5	4	3	2	1
autonomous/directed flag (a/d) baro/geo altitude (b/g) CPR Format even/odd (cprf) position uncertainty (nucp)	5	$nucp_4$	$nucp_3$	$nucp_2$	$nucp_1$	cprf	b/g	a/d	0
latitude (lat)	6	lat_8	lat_7	lat_6	lat_5	lat_4	lat_3	lat_2	lat_1
base altitude (balt)	7	$balt_{12}$	$balt_{11}$	$balt_{10}$	$balt_9$	lat_{12}	lat_{11}	lat_{10}	lat_9
	8	$balt_8$	$balt_7$	$balt_6$	$balt_5$	$balt_4$	$balt_3$	$balt_2$	$balt_1$
longitude (lng)	9	lng_8	lng_7	lng_6	lng_5	lng_4	lng_3	lng_2	lng_1
time figure of merit (tfom)	10	$tfom_2$	$tfom_1$	lng_{14}	lng_{13}	lng_{12}	lng_{11}	lng_{10}	lng_9
data age (da)	11	da_4	da_3	da_2	da_1	id_4	id_3	id_2	id_1
information field ID (id) ID extension 1 (id1), ID extension 2 (id2) ID extension 3 (id3)	12	id_{14}	id_{13}	id_{12}	id_{11}	id_{24}	id_{23}	id_{22}	id_{21}
	13	id_{34}	id_{33}	id_{32}	id_{31}	in_k			
information field (in)	14								
	15				. . . .				
	16								
	17	in_{14}	in_{13}	in_{12}	in_{11}	in_{10}	in_9	in_8	in_7
	18	in_6	in_5	in_4	in_3	in_2	in_1		

	. . . .		Denotes variable length field

E5.3.1 CPR encoding

(Manual on Detailed Technical Specifications App. E)

The Compact Position Reporting (CPR) algorithm was designed originally for use with Mode S bit encoding, with the purpose of allowing a full position report to be obtained using the smallest possible number of bits.

The raw latitude and longitude values from the aircraft's avionics are divided into CPR-encoded low-resolution components which are sent in the fixed part of the sync burst, and high-resolution offset components that may be sent with one or more of the different variable parts.

The low-resolution components are 12 bits in length for latitude and 14 bits in length for longitude, while the high-resolution offsets consist of either 4, 6, or 8 bits. The use of 14 bits for the low-resolution longitude encoding, as opposed to 12 for latitude encoding is to compensate for the fact that maximum errors in the longitude encoding were found to be approximately four times greater than those in the latitude encoding, with the longitude errors being highest near the polar regions.

To send position information, the CPR encoding algorithm is first used to encode the 12/14-bit low-resolution components in the fixed part of the synch burst - then the encoding for the high-resolution components is performed by adding an offset field to the position derived from the fixed position.

When a position report is received, the 12/14-bit low-resolution components are first decoded with the CPR algorithm. Depending on the resolution required, one of the high-resolution components may have been transmitted with the basic 12/14-bit transmission report. If so, the high-resolution component may be added to the 12/14-bit position to improve the overall resolution.

Single reports may be decoded if a reference position is already known. Alternate position reports are encoded slightly differently as either even format or odd format reports in order to permit globally unambiguous decoding by combining consecutively received reports of opposing format.

Thus:

- A single 12/14-bit encoded position report may be unambiguously decoded over a range of 1113 km (601 NM), with a resolution of approximately *140 m for latitude and *120 m for longitude. In this case, an observer or reference position must be known and be within *300.5 NM of the position to be decoded. The reference position will in most cases be the last globally unambiguous position to be decoded.
- A pair of 12/14-bit encoded position reports (i.e. one of even and one of odd format) may be unambiguously decoded globally, with a resolution of approximately *140 m for latitude and *120 m for longitude, when the two reported positions are separated by less than 15.9 km. For typical aircraft velocities (625 knots), this permits the use of odd and even position reports up to 50 seconds apart.

E5.4 Variable Data Fields

(Manual on Detailed Technical Specifications C.3)

Table E5-4: Variable part of the synchronisation burst

Information field	No of Bits	Encoding	Notes
Latitude	4	A high-resolution component to enhance the 12-bit low-resolution encoding transmitted in the fixed part	
Longitude	4	A high-resolution component to enhance the 14-bit low-resolution encoding transmitted in the fixed part	
Altitude offset	7	Barometric - geometric altitude Specific encoding defined in Manual on Detailed Technical Specifications C.10.	
UTC year	8	Current year - 1970, 0= N/A	1-255
UTC month	4	Linear	
UTC day	5	Linear; 00= N/A	
UTC hours	5	Linear	
UTC minute	6	Linear	
UTC second	6	Linear	
Slot	9	linear - 0 indicates the first slot in the second frame	0 to 255

Table E5-5: Link management information fields

Information field ID (id)	ID extension 1 (id1)	ID extension 2 (id2)	Information field name
3 hex	not present	not present	Basic ground
4 hex	not present	not present	UTC time

E5.4.1 Information Field Type 3 - Basic Ground

(Manual on Detailed Technical Specifications C.3)

A variable field to be transmitted by ground stations.

Table E5-6: Information field 3 hex - Basic ground

Description	Octet	Bit number							
		8	7	6	5	4	3	2	1
information field ID	11	x	x	x	x	0	0	1	1
UTC hours (h)	12	res	res	res	h_5	h_4	h_3	h_2	h_1
UTC minute (min)	13	pid_{10}	pid_9	min_6	min_5	min_4	min_3	min_2	min_1
patch ID (pid)	14	pid_8	pid_7	pid_6	pid_5	pid_4	pid_3	pid_2	pid_1
baro/geo offset (bgo)	15	slt_9	bgo_7	bgo_6	bgo_5	bgo_4	bgo_3	bgo_2	bgo_1
slot (slt)	16	slt_8	slt_7	slt_6	slt_5	slt_4	slt_3	slt_2	slt_1
4-bit longitude offset (lon4), 4-bit latitude offset (lat4)	17	$lon4_4$	$lon4_3$	$lon4_2$	$lon4_1$	$lat4_4$	$lat4_3$	$lat4_2$	$lat4_1$
UTC second (sec)	18	sec_6	sec_5	sec_4	sec_3	sec_2	sec_1		

“res” denotes currently unused. “x” denotes part of fixed data field.

E5.4.2 Information Field Type 4 - UTC Time

(Manual on Detailed Technical Specifications C.3)

Provides the possibility to transmit UTC time.

Table E5-7: Information field 4 hex - UTC Time

Description	Octet	Bit number							
		8	7	6	5	4	3	2	1
information field ID	11	x	x	x	x	0	1	0	0
UTC day (day)	12	res	res	res	day_5	day_4	day_3	day_2	day_1
UTC year (yr)	13	yr_8	yr_7	yr_6	yr_5	yr_4	yr_3	yr_2	yr_1
UTC hours (h), UTC month (mon)	14	h_4	h_3	h_2	h_1	mon_4	mon_3	mon_2	mon_1
UTC minute (min)	15	slt_9	h_5	min_6	min_5	min_4	min_3	min_2	min_1
slot (slt)	16	slt_8	slt_7	slt_6	slt_5	slt_4	slt_3	slt_2	slt_1
4-bit longitude offset (lon4), 4-bit latitude offset (lat4)	17	$lon4_4$	$lon4_3$	$lon4_2$	$lon4_1$	$lat4_4$	$lat4_3$	$lat4_2$	$lat4_1$
UTC second (sec)	18	sec_6	sec_5	sec_4	sec_3	sec_2	sec_1		

E5.5 Directory of Services (DoS) Message

The Directory of Services (DoS) message format is under final review by the AMCP VSG at this time, and will be included later in this appendix.

Attachment E6

ADS-B Implementation

This attachment comprises detailed information on the format of the ADS-B report. References to the draft VDL Mode Manual on Detailed Technical Specifications for the VDL Mode 4 Data Link are given.

ADS-B is implemented by combining information from the fixed part of the synchronisation burst (Attachment E5) and various ADS-B specific variable parts.

E6.1 Fixed Data Field

Information from the fixed part of the synchronisation burst is used in the implementation of ADS-B. See Attachment E5.

E6.2 Variable data fields

(Manual on Detailed Technical Specifications C.3)

In order to meet the RTCA MASPS requirements, a set of ADS-B variable information fields have been defined.

Table E6-1: ADS-B variable information fields

Information field	No of Bits	Encoding	Notes
NUCr	3	Values 0, 1, 2, 3, 4 in accordance with the five NUCr categories specified for ADS-B MASPS by RTCA/DO-242	Provides for the definition of 8 possible states
Latitude	4/6/8	A high-resolution component to enhance the 12-bit low-resolution encoding transmitted in the fixed part	Different possibilities for different variable parts
Longitude	4/6/8	A high-resolution component to enhance the 14-bit low-resolution encoding transmitted in the fixed part	Different possibilities for different variable parts
Altitude offset	7	Barometric - geometric altitude Specific encoding defined in VDL Mode Manual on Detailed Technical Specifications C.10	
Altitude rate flag	1	0 = barometric altitude rate 1 = geometric altitude rate	
Altitude rate	9/11	Linear encoding with a step of 100 fpm	1 bit is used as climb/descend flag (sign) and the other are used to provide a range of ±102150 fpm for the 11 bit case
Ground speed	11/13	Specific encoding is specified in VDL Mode Manual on Detailed Technical Specifications C.10	0 to 3070 knots for 11 bits and to 27640 for 13 bits. Variable step from 1 knot to 4 knots.
Ground track	11	0 = due North, Resolution is 360/2048 = 0.1757 degrees, linear	0° to 359.824° Note.- Ground track is the same as true track
Turn indication	2	0 = left, 1 = right, 2 = straight, 3 = unknown	
Patch ID	10	Encoding is described in VDL Mode Manual on Detailed Technical Specifications C.10	
Trajectory point/leg type	4	As per Mode S A.4.9.1	0-15
TCP data valid	1	0 = invalid 1 = valid	
TCP type	1	0 = current 1 = next	
TCP time to go	6	As per Mode S A.4.9.5	

Information field	No of Bits	Encoding	Notes
Callsign	42	Encoding for callsign: 1) Callsign shall be left justified 2) Only valid characters are A-Z, 0 - 9 and null: Assign A- Z = 0 - 25, 0 - 9 = 26 - 35, null = 36 3) Callsign shall be an eight character string "c_1, c_2, c_3, c_4, c_5, c_6, c_7, c_8" 4) $csl = c_1\ 36^3 + c_2\ 36^2 + c_3\ 36 + c_4$ 5) $csr = c_5\ 36^3 + c_6\ 36^2 + c_7\ 36 + c_8$	
Aircraft category	5		24 categories are specified in the MASPS
Aircraft status	3		8 categories are specified in the MASPS

Table E6-2: ADS-B information fields

Information field ID (id)	ID extension 1 (id1)	ID extension 2 (id2)	Information field name
0 hex	not present	not present	Basic
1 hex	not present	not present	High dynamic
2 hex	not present	not present	Full position
3 hex	not present	not present	Basic ground
4 hex	not present	not present	UTC time
5-9 hex			Available for future use
A hex	0 hex	not present	TCP
A hex	1 hex	not present	Call sign
A hex	2 - 9 hex	not present	Available for future use
A hex	A hex	0 hex	High resolution
A hex	A hex	1 - 9 hex	Available for future use
A hex	A hex	A hex	Extension (available for future use via further ID extension fields)
A hex	A hex	B - F hex	Available for future use
A hex	B - F hex	not present	Available for future use
B - E hex	not present	not present	Available for future use
F hex	not present	not present	No information field provided

Additional variable data fields are foreseen to meet long term European ATM concept requirements.

E6.2.1 Information Field 0 - Basic

(Manual on Detailed Technical Specifications C.3)

This is the basic information field for transmission in most sync bursts from mobile stations.

Table E6-3: Information field 0 hex - Basic

Description	Octet	Bit number							
		8	7	6	5	4	3	2	1
information field ID	11	x	x	x	x	0	0	0	0
rate uncertainty (nucr) 6-bit latitude offset (lat6)	12	$nucr_2$	$nucr_1$	$lat6_6$	$lat6_5$	$lat6_4$	$lat6_3$	$lat6_2$	$lat6_1$
6-bit longitude offset (lon6) baro rate/geo rate (br/gr)	13	$nucr_3$	br/gr	$lon6_6$	$lon6_5$	$lon6_4$	$lon6_3$	$lon6_2$	$lon6_1$
baro/geo offset (bgo)	14	$altr_9$	bgo_7	bgo_6	bgo_5	bgo_4	bgo_3	bgo_2	bgo_1
altitude rate (altr)	15	$altr_8$	$altr_7$	$altr_6$	$altr_5$	$altr_4$	$altr_3$	$altr_2$	$altr_1$
ground speed (gs)	16	gs_8	gs_7	gs_6	gs_5	gs_4	gs_3	gs_2	gs_1
ground track (gt)	17	gs_{11}	gs_{10}	gs_9	gt_5	gt_4	gt_3	gt_2	gt_1
	18	gt_{11}	gt_{10}	gt_9	gt_8	gt_7	gt_6		

“x” denotes part of fixed data field.

E6.2.2 Information Field 1 - High Dynamic

(Manual on Detailed Technical Specifications C.3)

Provides higher resolution for faster moving aircraft.

Table E6-4: Information field 1 hex - High dynamic

Description	Octet	Bit number							
		8	7	6	5	4	3	2	1
information field ID	11	x	x	x	x	0	0	0	1
baro rate/geo rate (br/gr), baro/geo offset (bgo)	12	br/gr	bgo_7	bgo_6	bgo_5	bgo_4	bgo_3	bgo_2	bgo_1
altitude rate (altr)	13	$altr_8$	$altr_7$	$altr_6$	$altr_5$	$altr_4$	$altr_3$	$altr_2$	$altr_1$
	14	$altr_{11}$	$altr_{10}$	$altr_9$	hgs_{13}	hgs_{12}	hgs_{11}	hgs_{10}	hgs_9
high-res ground speed (hgs)	15	hgs_8	hgs_7	hgs_6	hgs_5	hgs_4	hgs_3	hgs_2	hgs_1
4-bit longitude offset (lon4), 4-bit latitude offset (lat4)	16	$lon4_4$	$lon4_3$	$lon4_2$	$lon4_1$	$lat4_4$	$lat4_3$	$lat4_2$	$lat4_1$
ground track (gt)	17	gt_8	gt_7	gt_6	gt_5	gt_4	gt_3	gt_2	gt_1
rate uncertainty (nucr)	18	gt_{11}	gt_{10}	gt_9	$nucr_3$	$nucr_2$	$nucr_1$		

“x” denotes part of fixed data field.

E6.2.3 Information Field 2 - Full Position

(Manual on Detailed Technical Specifications C.3)

Provides an unambiguous global position.

Table E6-5: Information field 2 hex - Full position

Description	Octet	Bit number							
		8	7	6	5	4	3	2	1
information field ID	11	x	x	x	x	0	0	1	0
6-bit latitude offset (lat6)	12	pid_{10}	pid_9	$lat6_6$	$lat6_5$	$lat6_4$	$lat6_3$	$lat6_2$	$lat6_1$
patch ID (pid)	13	pid_8	pid_7	pid_6	pid_5	pid_4	pid_3	pid_2	pid_1
baro/geo offset (bgo)	14	gt_{11}	bgo_7	bgo_6	bgo_5	bgo_4	bgo_3	bgo_2	bgo_1
6-bit longitude offset (lon6)	15	gt_{10}	gt_9	$lon6_6$	$lon6_5$	$lon6_4$	$lon6_3$	$lon6_2$	$lon6_1$
ground track (gt)	16	gt_8	gt_7	gt_6	gt_5	gt_4	gt_3	gt_2	gt_1
ground speed (gs)	17	gs_8	gs_7	gs_6	gs_5	gs_4	gs_3	gs_2	gs_1
rate uncertainty (nucr)	18	gs_{11}	gs_{10}	gs_9	$nucr_3$	$nucr_2$	$nucr_1$		

“x” denotes part of fixed data field.

E6.2.4 Information Field Type A0 - TCP

(Manual on Detailed Technical Specifications C.3)

Provides the possibility to transmit a trajectory change point (TCP).

Table E6-6: Information field A0 hex - TCP

Description	Octet	Bit number							
		8	7	6	5	4	3	2	1
information field ID	11	x	x	x	x	1	0	1	0
TCP data type (type)	12	0	0	0	0	res	type	ttg_6	ttg_5
time to go (ttg)	13	$balt_{12}$	$balt_{11}$	$balt_{10}$	$balt_9$	ttg_4	ttg_3	ttg_2	ttg_1
base altitude	14	$balt_8$	$balt_7$	$balt_6$	$balt_5$	$balt_4$	$balt_3$	$balt_2$	$balt_1$
latitude (lat)	15	lat_8	lat_7	lat_6	lat_5	lat_4	lat_3	lat_2	lat_1
	16	lat_{12}	lat_{11}	lat_{10}	lat_9	lng_{12}	lng_{11}	lng_{10}	lng_9
longitude (lng)	17	lng_8	lng_7	lng_6	lng_5	lng_4	lng_3	lng_2	lng_1
CPR even/odd (cprf), trajectory point/leg type (p/l)	18	cprf	p/l_4	p/l_3	p/l_2	p/l_1	res		

“res” denotes currently unused. “x” denotes part of fixed data field.

E6.2.5 Information field type A1 - call sign

(Manual on Detailed Technical Specifications)

Contains the aircraft call sign.

Table E6-7: Information field A1 hex - Call sign

Description	Octet	Bit number							
		8	7	6	5	4	3	2	1
information field ID	11	x	x	x	x	1	0	1	0
aircraft category (ac)	12	1	0	1	0	ac_4	ac_3	ac_2	ac_1
status (st)	13	ac_5	st_3	st_2	st_1	csl_{12}	csl_{11}	csl_{10}	csl_9
call sign left (csl)	14	csl_8	csl_7	csl_6	csl_5	csl_4	csl_3	csl_2	csl_1
	15	csl_{20}	csl_{19}	csl_{18}	csl_{17}	csl_{16}	csl_{15}	csl_{14}	csl_{13}
call sign right (csr)	16	csl_{21}	csr_7	csr_6	csr_5	csr_4	csr_3	csr_2	csr_1
	17	csr_{15}	csr_{14}	csr_{13}	csr_{12}	csr_{11}	csr_{10}	csr_9	csr_8
	18	csr_{21}	csr_{20}	csr_{19}	csr_{18}	csr_{17}	csr_{16}		

E6.2.6 Information field AA0- high resolution

(Manual on Detailed Technical Specifications C.3)

This is dedicated for use by high-performance aircraft.

Table E6-8: Information field AA0 hex - High resolution

Description	Octet	Bit number							
		8	7	6	5	4	3	2	1
information field ID	11	x	x	x	x	1	0	1	0
	12	1	0	1	0	0	0	0	0
turn indication (tind)	13	res	res	res	gs_{11}	gs_{10}	gs_9	$tind_2$	$tind_1$
ground speed (gs)	14	gs_8	gs_7	gs_6	gs_5	gs_4	gs_3	gs_2	gs_1
8-bit longitude offset (lon8)	15	$lon8_8$	$lon8_7$	$lon8_6$	$lon8_5$	$lon8_4$	$lon8_3$	$lon8_2$	$lon8_1$
8-bit latitude offset (lat8)	16	$lat8_8$	$lat8_7$	$lat8_6$	$lat8_5$	$lat8_4$	$lat8_3$	$lat8_2$	$lat8_1$
ground track (gt)	17	gt_8	gt_7	gt_6	gt_5	gt_4	gt_3	gt_2	gt_1
rate uncertainty (nucr)	18	gt_{11}	gt_{10}	gt_9	$nucr_3$	$nucr_2$	$nucr_1$		

"res" denotes currently unused. "x" denotes part of fixed data field.

Table E6-9: Summary of ADS-B message formats

	Periodic (P) / On request (R)	Variable ID	Total number of bits	Spare bits	Synch burst header, CRC	Message ID	Variable part ID	Extended Variable part ID	Periodic reservation data	Autonomous/ Directed flag	Position uncertainty	Rate uncertainty	Patch ID	CPR Odd/ Even flag	Latitude	Latitude offset	Longitude	Longitude offset	Baro/ Geo altitude	Base altitude	Baro / Geo offset	Baro rate / Geo rate	Altitude rate
Fixed	-		114	0	58	1	4		10	1	4			1	12		14		1	12			
Variable																							
- Basic	P	0	54	0				0				3				6		6			7	1	9
- High Dynamic	P	1	54	0				0				3				4		4			7	1	11
- High Resolution	P	2720	54	3				8				3				8		8					
- Full position	R	2	54					0				3	10			6		6			7		
- Call sign	PR	161	54					4															
- TCP	PR	160	54	2				4															
- Basic Ground	P	3	54	3				0					10			4		4			7		
- UTC Time	R	4	54	3				0								4		4					

	Ground speed	High resolution ground speed	Ground track	Turn indication	Time Figure of Merit	Data age	Aircraft category	Aircraft status	Aircraft callsign	TCP data type	TCP Time to go	TCP Altitude	TCP Latitude	TCP Longitude	TCP CPR Odd/ Even flag	TCP point/ leg type	UTC year	UTC month	UTC day	UTC hours	UTC minute	UTC second	Slot number
Fixed					2	4																	
Variable																							
- Basic	11		11																				
- High Dynamic		13	11																				
- High Resolution	11		11	2																			
- Full position	11		11																				
- Call sign							5	3	42														
- TCP										1	6	12	12	12	1	4							
- Basic Ground																				5	6	6	9
- UTC Time																	8	4	5	5	6	6	9

Table E6-10: Transmission rates

Transmission type	**Effective transmission rate**	**Originator**	**Message**
ADS-B position report	Varies between 1.5-10 sec (See Chapter 6)	Aircraft	Fixed and basic Fixed and high dynamic Fixed and high resolution
Aircraft trajectory change point (TCP)	Once 2.5 or 5 min and on request	Aircraft	Fixed and TCP
Aircraft data and status	Once per 5 min and on request	Aircraft	Fixed and call sign
ADS-B full position	On request	Aircraft	Fixed and full position
UTC time and ground station position	Once per 60 sec	Ground station	Fixed and basic ground
Full UTC time	On request	Aircraft Ground station	Fixed and UTC time

Draft TIS-B Application Specification for a Test System Using STDMA 9,6 kbps

E7.1 Introduction

E7.1.1 General

This paper describes the specification for a Traffic Information Service Broadcast (TIS-B) application for the testing of TIS-B with prototype VDL Mode 4/STDMA equipment using a data rate of 9,6 kbps. The TIS-B implementation is specific to the tests, although it may be generalized to other systems in the future.

E7.1.2 Overview

TIS-B is a ground broadcast application and involves the processing of aircraft position information from, for example, radar, and re-broadcasting the positions to aircraft via a data-link. In the test, the data link is STDMA (Self-Organising Time Division Multiple Access).

The objective of TIS-B is to provide for broadcast transmission of ATC traffic information detected by independent surveillance means (PSR+SSR). This service is to be guaranteed in the area covered by the base station transmitters.

Both primary and secondary radar may be used to provide surveillance data. With primary radar, only target 2-D positions are available. With secondary radar, aircraft barometric altitude and transponder identity code (Mode A code) are also available. In the test system, a multi-radar processing system produces a single surveillance picture from various radar sources.

The surveillance picture is passed to the air-to-ground data link data, ready for re-broadcast as TIS-B data. Aircraft in range of TIS-B transmissions and with the appropriate receiving and decoding equipment, process the surveillance data, and display the aircraft position information in the cockpit for use by pilots. The scenario is illustrated in Figure E7-1.

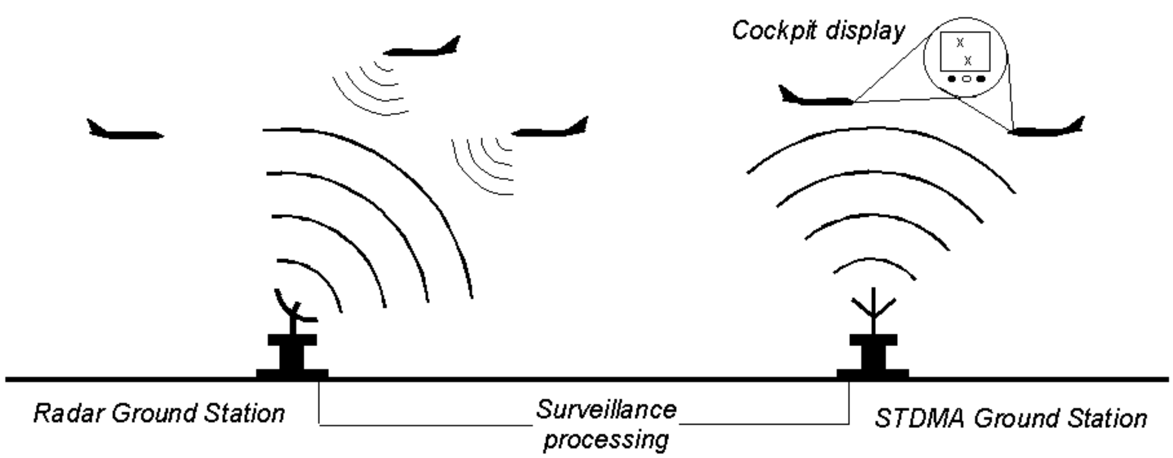


Figure E7-1: TIS-B application

TIS-B is an up-link broadcast application. It does not involve any transmissions from aircraft.

E7.2 Description of TIS-B Service

E7.2.1 General

The ground surveillance processing shall provide to the communications infrastructure a surveillance picture. This picture shall contain the following information on aircraft targets:

- Mode A code (identity)
- Latitude
- Longitude
- Altitude (as reported in the Mode C code at 100ft intervals)
- Ground track angle
- Ground speed

The ground surveillance processing shall update each target every 10s in en-route flight and 5s in the terminal area or at lower altitudes.

There shall be three types of uplink message that shall be transmitted with different rates:

- Reference message: This shall contain information that describes the TIS-B service and, in the future, other relevant information. In the test project, the reference message only contains a version number, indicating the version of the TIS-B service and a reference point giving the precise latitude/longitude location of a point to which the service volume points are measured.
- Service volume message: This shall contain information on the ‘service volume’ in which TIS-B is provided. The service volume is an area in which all surveillance targets are uplinked. The purpose of the service volume is to inform the pilot as to where full airborne surveillance is available. Each ground station transmits target information in one service volume only. The ground station transmits information on all targets in the service volume and none on targets outside of the service volume.
- Target message: This shall contain information on one or more aircraft targets. The information shall be: Mode A code, Latitude relative to reference point, Longitude relative to reference point, ground track angle, ground speed and Mode C code.

The reference and surveillance volume messages shall be transmitted at least once every 30s. They may also be transmitted at higher rates.

E7.2.2 Service volume

In test program, each ground station can support only one service volume. The service volume information contained in the reference message shall contain the following information:

- maximum altitude of the service volume;
- minimum altitude of the service volume;
- 5 corner points (latitude and longitude) that describe the outside of the volume.

The corner points shall be transmitted in clockwise order. If fewer than 5 points are required to describe the edge of the volume, then the last point shall be repeated until the total number transmitted is 5. The corner points are transmitted as relative latitude/longitude offsets to the reference point given in the reference message. The altitudes of the service volume are transmitted as absolute values.

E7.3 Messages

E7.3.1 Overview

This section describes the messages that shall be uplinked from each ground station. The message formats described here shall be converted to ASCII HEX strings that shall be used in the ground network. The ground station shall convert the messages to a binary format before transmitting and an airborne station shall convert them back to the ASCII format before outputting them.

E7.3.2 Ground network message formats

New STDMA message formats have been created for the tests and these are listed in Section E7.7. All TIS-B messages are defined in HEX format. The character coding for these characters used in the ground network are based on ASCII HEX (characters 0-9 and A-F). Each ASCII HEX character is converted to 4 binary bits when transmitted over the data link.

E7.3.3 Reference message

The reference message shall consist of the following fields:

Field no.	Description	Format
1	Version	1 ASCII HEX Character. 01 = TIS-B version 1.
2	Reference point latitude	6 ASCII HEX Characters. Units: 1/100 minutes. Range: ±90 degrees (i.e. -540 000 to 540 000). Positive = North hemisphere. Negative = South hemisphere
3	Reference point longitude	6 ASCII HEX Characters. Units: 1/100 minutes. Range: ±180 degrees (i.e. +1080 000 to 1080 000). Positive = East. Negative = West

E7.3.4 Service volume message

The service volume message shall consist of the following fields:

Field no.	Description	Format
1	SV minimum altitude	3 ASCII HEX Characters. Units: 100 feet. Range: 0 - 40 000.
2	SV maximum altitude	3 ASCII HEX Characters. Units: 100 feet. Range: 0 - 40 000.
3	SV corner 1, relative latitude	5 ASCII HEX Characters. Units: 1/100 minutes. Range: ±10 degrees (i.e. -60 000 to +60 000). Positive = North hemisphere. Negative = South hemisphere
4	SV corner 1, relative longitude	5 ASCII HEX Characters. Units: 1/100 minutes. Range: ±20 degrees (i.e. -120 000 to +120 000). Positive = East. Negative = West

5	SV corner 2, relative latitude	5 ASCII HEX Characters. Units: 1/100 minutes. Range: ±10 degrees (i.e. -60 000 to +60 000) Positive = North hemisphere. Negative = South hemisphere
6	SV corner 2, relative longitude	5 ASCII HEX Characters. Units: 1/100 minutes. Range: ±20 degrees (i.e. -120 000 to +120 000). Positive = East. Negative = West
7	SV corner 3, relative latitude	5 ASCII HEX Characters. Units: 1/100 minutes. Range: ±10 degrees (i.e. -60 000 to +60 000) Positive = North hemisphere. Negative = South hemisphere
8	SV corner 3, relative longitude	5 ASCII HEX Characters. Units: 1/100 minutes. Range: ±20 degrees (i.e. -120 000 to +120 000). Positive = East. Negative = West
9	SV corner 4, relative latitude	5 ASCII HEX Characters. Units: 1/100 minutes. Range: ±10 degrees (i.e. -60 000 to +60 000) Positive = North hemisphere. Negative = South hemisphere
10	SV corner 4, relative longitude	5 ASCII HEX Characters. Units: 1/100 minutes. Range: ±20 degrees (i.e. -120 000 to +120 000). Positive = East. Negative = West
11	SV corner 5, relative latitude	5 ASCII HEX Characters. Units: 1/100 minutes. Range: ±10 degrees (i.e. -60 000 to +60 000) Positive = North hemisphere. Negative = South hemisphere
12	SV corner 5, relative longitude	5 ASCII HEX Characters. Units: 1/100 minutes. Range: ±20 degrees (i.e. -120 000 to +120 000). Positive = East. Negative = West

Notes:

- SV = Service Volume
- The total length of the message is 56 ASCII characters. When encoded into binary format for data link transmission, this part of the message has a length of around 224 bits.
- Each relative latitude/longitude (SV corner) is measured relative to the reference point.
- This message requires 2 STDMA timeslots to transmit.

E7.3.5 Target message

The target message shall consist of one or more aircraft tracks. The format of each track is as follows:

Field no.	Description	Format
1	Mode A code	12 bits Units: integer. Range: 0 - 4095.
2	Altitude (Mode C code)	12 bits Units: 100 feet. Range: 0 - 40 950 ft
3	Relative latitude	17 bits according to CPR encoding.
4	Relative longitude	17 bits according to CPR encoding.
5	Format/Time bits	2 bits, used in CPR encoding.
6	Ground track angle	6 bits. Units: 6 degrees. Range: 0 - 360.
7	Ground speed	5 bits Units: 20 knots. Range: 0 - 640

Notes:

- The 2-D position (latitude, longitude and Format/Time bits) is encoded according to the Compact Position Reporting (CPR) system described in the "Manual of Mode S Specific Services", version 2, May 1999. Under this scheme, 17 bits are used each for latitude and longitude and two bits are used for format/time indications.
- To decode a target that is CPR encoded, it is necessary to receive the target twice in consecutive surveillance picture. (To allow unambiguous decoding, it is necessary to receive two consecutive reports within about 10s of each other. Since the surveillance picture is uplinked every 10s maximum, this means that targets in consecutive pictures must be correlated. Note that this assumes that aircraft fly slower than 1000kt, as described in the Manual of Mode S Specific Services.)
- When it is converted into a binary format, each track requires 71 bits.
- A 1-target message requires one STDMA timeslot for transmission. Messages containing 2, 3, 4 or 5 targets require 2 STDMA slots to transmit.

A target message shall consist of the following fields:

Field no.	Description	Format
1	Number of tracks	3 bits. Range: 1-5.
2	Aircraft track	71 bits. Various contents - see above
3	(Aircraft track)	71 bits. Various contents - see above. Only if number of tracks >1.
4	(Aircraft track)	71 bits. Various contents - see above. Only if number of tracks = >2.
5	(Aircraft track)	71 bits. Various contents - see above. Only if number of tracks = >3.
6	(Aircraft track)	71 bits. Various contents - see above. Only if number of tracks = 5.

Notes:

- Each target message may contain 1, 2, 3, 4 or 5 tracks.
- The binary target message is converted into ACSII HEX by converting each 4-bits into a single ASCII character.
- The length of a 5 track message is 358 bits or 90 ASCII HEX characters when converted.

E7.4 Ground Function Allocations

E7.4.1 Overview

This section describes what functions shall be performed in each part of the ground system. The following figure shows the physical architecture of ground systems and the developers responsible for each element.

Figure E7-2: Ground system physical architecture

E7.4.2 Surveillance system

The surveillance system shall generate target information and pass it to the communications system for processing, filtering and transmission. Each target information passed to the communications system shall be uplinked once (and not repeated). The ground surveillance system shall ensure that the same target is not passed to more than one API. The surveillance system shall generate target information at the following rates:

- once per 10 s for aircraft in en route airspace (i.e. above 3000m),
- once per 5 s for aircraft in the terminal area (i.e. between 1000m and 3000).

Information for aircraft below 1000 m shall only be used where full surveillance cover is available below 100 m. Where surveillance information for aircraft below 100m is used, this shall be updated once per 5s.

The service volume altitude shall be selected so that full surveillance cover is always available in the whole service volume. For example, around radar stn 1 a service volume may be defined with a minimum altitude of 500m while the service volumes away from radar stn 1 could have a minimum altitude of, eg, 1000m.

E7.4.3 Ground network

The ground network shall perform the following functions:

- filter data
- generate reference messages
- pack into uplink format
- pass to ground station

The entry to the ground network will be at an API (Application Program Interface). The API is a library of C-language functions that is the interface to the communications functions. The API is resident on an Alenia UNIX workstation.

The API is linked to a TIS-B Distribution Service (TDS) that is a Windows NT service running on a separate PC. Other processes also run on this PC, including the Local Server and possibly the Sub-Domain Server. The TDS produces all the TIS-B messages and forwards these to the appropriate STDMA ground station.

Each TDS shall have knowledge of all service volumes and shall forward any target to the appropriate ground station (local or remote) for uplinking. The TDS shall pack a small number of targets together to form a single message where possible. To process targets, the TDS shall:

- maintain a queue of targets for each base station (each targets shall be timestamped with the time that it was added to the queue);
- determine the destination of each target message and add it to the appropriate queue;
- when it receives an 'end of surveillance picture' message from the surveillance system, it shall pack all targets in each queue and send to the appropriate ground station.

The TDS shall send messages to the ground station at a pre-determined rate that shall prevent overload of the ground station and the serial communications to the ground stations. The TDS shall generate reference messages and service volume messages at the following rates:

- One reference message per 30 seconds;
- One service volume message per 10 seconds.

E7.4.4 Ground station functions

The ground station shall perform the following functions:

- reserve slots for the TIS-B messages,
- manage the transmission of messages in slots, including queuing messages until a slot becomes available,
- convert messages the ground network format into the binary data link format,
- transmit the messages.

Note: The format used for message transmission is attached in Section E7.7.

The ground station shall keep a queue of target and service volume messages while it waits for slots to become available to transmit the message. When slots are available, it shall transmit the messages.

In the case of the test project, the ground station does not re-broadcast ADS-B reports received from ADS-B equipped aircraft. However, in other projects, it may do so. If it does, then the aircraft display shall process both data. The aircraft display processor shall be aware of the duplication because both positions shall be accompanied by the same aircraft address.

The ground station shall manage the blocking of slots on the data link channel. The blocking approach is described in Section E7.7.

Note that TIS-B messages shall be restricted to the VHF channel 136.900 MHz and all other messages shall be transmitted only on 136.950 MHz:

- Channel A: 136.950 MHz: ADS-B (basic and extended), DGNSS, all free text messages (uplink and downlink).
- Channel B: 136.900 MHz: TIS-B messages (reference, service volume and targets).

E7.4.5 Airborne station functions

The airborne data link station shall perform the following functions:

- receive the TIS-B messages,
- convert them back into the ground network format,
- pass the received messages to the output serial port in the ASCII format.

E7.5 Cockpit Display/Processing Functions

The display design should take into account the following requirements when presenting uplinked TIS-B data to the pilot:

- The display shall re-construct actual aircraft positions from the reference and target messages provided by the airborne station (mobile transponder);
- The display shall only show target information for aircraft that are within a received service volume and for which the appropriate reference message has been received;
- Several ground stations may be transmitting in an area, so the display shall always correlate aircraft with the correct ground station by comparing the ground station address of all transmissions;
- The display shall indicate the 'TIS-B service volume' for each ground station.
- If the same position report is received from several ground stations, the most recent shall be displayed (this will be apparent if the same target Mode A code is received from 2 or more ground stations). The display processor may perform a 'consistency check' on aircraft positions that are received from more than one ground station.
- The display processor shall perform an integrity check on target data received from different sources (i.e. TIS-B and ADS-B).
- The display shall indicate the aircraft identity (Mode A code) if required by the pilot.
- The display shall not show aircraft until the reference message and service volume message is received. However, the display processor may store the callsigns of aircraft for use when the reference position is received. It may also store position reports and display these if they are not older than a certain time (T_1 - see below).
- The display shall indicate if a position report is older than a time (T_1). After a further time (T_2) without an updated position report, the aircraft status shall be changed to "surveillance lost". After a further time (T_2) without an updated position report the aircraft shall either be removed from the display. The following table gives default values for these parameters:

Parameter	Description	Value
T_1	Time until 'old position report' is indicated	30 s
T_2	Time until 'surveillance lost' is indicated	30 s
T_3	Time until aircraft is removed from display	60 s

E7.6 Possible future enhancements

This note has described a TIS-B implementation for the test project. In a future implementation, several enhancements could be made:

- Uplink of additional target information, including 24-bit aircraft address, turn rate, vertical rate and aircraft callsign instead of Mode A code. The identity information could be transmitted at a lower rate than the position information.
- More than one service volume supported per ground station. Each service volume will need a unique identifier.
- Add the ICAO identifier of the ATSU that is providing the TIS-B service to the reference message.
- More than 5 points in each service volume description.
- Add information on the surveillance source of the TIS-B data (e.g. radar, ADS + radar, etc). This information is required by the aircraft systems if they are to be able to correctly fuse TIS-B and ADS-B data.

E7.7 Data Link Implementation

This section describes the details of the STDMA data link implementation used for TIS-B message transmission.

E7.7.1 Slot reservation

Each ground station will use a blocking message (type 130) to reserve a number of slots in each second for TIS-B. The blocking message shall be transmitted once every alternate seconds, with the reference message transmitted in the same slot in the alternate second. The reserved slots (i.e. all slots following the first slot) will be used for the service volume and target messages.

The number of slots reserved by each ground station and the position of these within the second shall be configurable in the ground station. The default values number of slots reserved in the test project shall be:

- Radar stn 1 ground station: 15 slots (including the blocking message)
- Radar stn 2 and radar stn 3 ground stations: 11 slots each (including blocking message).

E7.7.2 Message formats

Messages passed into the ground station shall use the format:

$PRGPS,I,,0,MMMM…

where:

I = identifier of the message passed into the ground station

MMMM… = the message content

Messages produced by an airborne station and passed to the CDNU shall use the format:

$OAAAAAAAAMMMM…

where:

O = identifier of the message passed into the ground station

AAAAAAAA = address of transmitting ground station

MMMM… = the message content

The following table gives the codes of each message:

	Target message	**Reference message**	**Service volume message**
Identifier of message passed into ground station (I) to send message on: channel A channel B	 013 014	 015 016	 017 018
Identifier of message produced by airborne station (O)	T	R	V
Radio message type (used only on radio link)	131	132	133

The following example messages illustrate the coding system for a target message from ground station @ESSAB01 on Channel B starting with E1AB…. :

- Target message to be transmitted on channel B: $PRGPS,014,0,E1AB…
- Target message passed from airborne station to CDNU: $T@ESSAB01E1AB…

Summary Table of Selected Technical Characteristics of Link Candidates

Characteristic	1090 MHz Extended Squitter		VDL Mode 4		UAT	
	Proposed Operational System	1999 U.S. Tests	Proposed Operational System	1999 U.S. Tests	Proposed Operational System	1999 U.S. Tests
Frequency Band	1090 MHz	Same	108-136.975 MHz	112-118 MHz	960-1215 MHz	966 MHz
Bit Rate	1 Megabit/sec	Same	19200 bits/sec/channel	Same	1.041667 Megabits/sec	Same
Modulation	PPM	Same	Binary GFSK $\pm$2400 Hz	Same	Binary GFSK $\pm$312.5 KHz	Same
Synchroni-zation	4 pulse preamble (9 pulse processing)	Same	First 24 bits	Same	First 36 bits	Same
Message Length	112 bits	Same	192 bits after synchronization	Same	246 bits, short 372 bits, long	Same
Parity	24 bits	Same	16 bits	Same	48 bits FEC and 24 bits CRC	Same
Address	24 bits	Same	3+24 bits	Same	25 bits	Same
Airborne Longitude	CPR 17 bits, even 17 bits, odd LSB ~5 meters	Same	Compressed 18-22 bits even 16-20 bits odd LSB ~1-18 meters	Same	Uncompressed 24 bits LSB = 2.3 meters	Same
PVT Segmentation?	Yes: Velocity in separate message	Same	No: PVT in one message	Same	No: PVT in one message	Same
Transmitter Power (at Antenna)	51-57 dBm, high-end 48.5-57 dBm, low-end	Same	41-47 dBm, high-end 37-43 dBm, medium 34-40 dBm, ow-end	44, 39.8, and 37.8 dBm	46-48 dBm, high-end 40-42 dBm, low-end	41 dBm +/- 3 dB
Receiver MTL (90%) (at Antenna)	$\leq$ -84 dBm, high end $\leq$ -74 dBm, low-end	~-79 to ~-87 dBm	$\leq$ -103 dBm at 10^{-4} BER	-80 and -90 dBm at 1% MER	$\leq$ -92 dBm	-91 dBm
Polarization	Vertical	Same	Vertical	Same	Vertical	Same
Transmission Rate for PVT	Position at 2 Hz Velocity at 2 Hz	Same	PVT every 10 sec. Enroute PVT every 5 sec. Terminal PVT every ~1.5 sec. with local channels	PVT every 1 second	PVT every 1 second	Same
Transmission Rate for Intent/Flight Ident.	2.2 per second	0.2 per second	Each TCP once every 2.5 minutes Flight Ident. Once every 5 minutes	Not transmitted	Within same message as PVT	Flight Ident. Transmitted
Multiple Access Technique	Random messages	Same	Self-organizing TDMA (75 slots/second per channel)	Same	Slots to separate ground/air. Aircraft use random messages	Same
RF Channels	One channel	Same	2 (25KHz) Global Signaling Channels, plus up to 2 local channels	2 Channels (Used as if Global)	One Channel	Same

Acronyms:

BER	Bit Error Rate
CPR	Compact Position Reporting (Compression)
CRC	Cyclic Redundancy Code
FEC	Forward Error Correction
GFSK	Gaussian Frequency Shift Keying
LSB	Least Significant Bit
MER	Message Error Rate
MTL	Minimum Trigger Level
PPM	Pulse Position Modulation
PVT	Position, Velocity and Time (Information for ADS-B State Vector)
RF	Radio Frequency
TCP	Trajectory Change Point
TDMA	Time Division Multiple Access

Appendix G

Link Evaluation Criteria

Technical link evaluation criteria development to support Safe Flight 21 applications proceeded in the following manner:

Step 1: Define industry consensus reference documents upon which to base the link evaluation criteria.

The Safe Flight 21 Steering Committee approved the use of two reference documents:

Joint Government/Industry Plan for Free Flight Operational Enhancements, August 1998, RTCA Free Flight Select Committee
RTCA DO-242, Minimum Aviation System Performance Standards (MASPS) for ADS-B

The SF21 Steering Committee also approved the use of any additional requirements documents that Eurocontrol might wish to add to the above. Eurocontrol, while supplying a number of useful planning and surveillance-related documents to the LET, has indicated that European requirements development for ADS-B is not yet complete, and that Eurocontrol is not at present in a position to add further reference documents into the evaluation process.

The LET notes that its VDL Mode 4 subject matter experts, EUROCAE, and Eurocontrol have consistently taken the view that the RTCA ADS-B MASPS, while an important document, has not been adopted within Europe and therefore should not be viewed as definitive with regard to, for example, requirements for ADS-B report content and update rates. RTCA and EUROCAE are considering joint development of an update to DO-242. The LET cannot assess what changes, if any, might be made to DO-242 in this or other regards.

Step 2: Identify appropriate MASPS requirements to be used as evaluation criteria for the candidate links Define common traffic and environmental scenarios for link evaluation.

Attachment 1, an excerpt from a presentation made in March 1999 to the SF21 Steering Committee, outlines how the appropriate MASPS requirements were identified. Additionally, the Steering Committee confirmed that support by the link candidates for the simultaneous parallel approach scenario of the MASPS needed to be assessed. Attachment 2 summarizes the identified MASPS requirements.

The LET developed a consensus set of traffic scenarios for U.S. and Europe, based on team member inputs and engineering judgement.

Step 3: Develop additional further technical criteria not covered by the MASPS but needed to support the Free Flight Operational Enhancements.

Consideration of the Operational Enhancements made it clear that requirements related to the support of TIS-B and FIS-B services, which are not in the ADS-B MASPS, would need to be developed. Following the definition by the LET of a strawman operational concept for TIS-B, requirements were derived to assess the impact on each link of supporting this function. These derived requirements were approved by the SF21 Steering Committee. Attachment 3 is an excerpt from a presentation made to the Steering Committee that outlines recommended TIS-B requirements to be adopted as evaluation criteria for the candidate links.

With regard to FIS-B requirements, the LET considered the draft MASPS for FIS-B under development by RTCA as well as FIS-B spectrum requirements discussed in RTCA DO-237. Additionally, the SF21 Steering Committee provided a prioritization of FIS-B services (e.g., weather information) to assist the LET in its development of requirements. The LET developed a data link requirement for FIS-B on the order of 200 bits/second, delivered, for the FIS-B information for a single airport.

Additional technical evaluation criteria to those found in the ADS-B MASPS or those required to support TIS-B and FIS-B were seen by the LET and Steering Committee to be a necessary component of the LET's considerations. These requirements, referred to as "implied requirements", are outlined in Attachment 1. While evaluation to "implied" criteria necessarily involves some subjectivity, the considerations involved are technical and therefore were deemed appropriate to the LET. With regard to the implied requirement for "Time to Spectrum Availability", the LET's assessment was performed by its members from the FAA Office of Spectrum Policy and Management.

Excerpt from March 1999 LET Presentation Made to the Safe Flight 21 Steering Committee

Approval of ADS-B Link Evaluation Criteria

SF 21 Link Evaluation Criteria

- Reference Documents
- Evaluation Criteria Development Approach
- Draft Link Evaluation Criteria: "Derived" (from FF Operational Enhancements) , "MASPS-Derived",and "Implied"
- Recommend Approval of ADS-B-Related Evaluation Criteria. TIS/TIS(B) and FIS/FIS(B) Criteria to be proposed in April.

Reference Documents (* = Currently Approved)

- Joint Government/Industry Plan for Free Flight Operational Enhancements, 8/98*
- ADS-B MASPS, DO-242*
- Open Issue: References for TIS/TIS-B/FIS/FIS-B. RTCA DO-239 Covers TIS on 1090 MHz. Draft MASPS on FIS-B and Faraway II Specification for TIS-B.
- European Consensus Documents In Review

Evaluation Criteria Development With Approved References

- For each FF Operational Enhancement:
  - Determine whether there is a requirement on the ADS-B/Situational Awareness Link
  - If so, take MASPS requirements directly
  - If MASPS is not applicable (e.g., TIS/FIS), identify suitable requirements
- Identify additional technical evaluation criteria: “MASPS-Derived” and “Implied”

FF Operational Enhancements: Derived Link Requirements

- Random Off-Airway Navigation Using GPS: No Derived Link Requirements
- FIS for SUA Status, Weather, Wind-Shear, NOTAMs, PIREPS: Need requirements--FIS-B MASPS in draft from RTCA SC-169
- CFIT Avoidance and Situational Awareness: No Derived Link Requirements

FF Operational Enhancements: Derived Requirements (Ctd.)

- Improved Terminal Operations in Low Visibility Conditions: ADS-B MASPS Table 3-4, First 2 Columns, First 5 Rows. TIS Requirements under Review
- Enhanced Visual Operations and Situational Awareness: ADS-B MASPS, Table 3-4, First Column, First 5 Rows. TIS Requirements under Review.

FF Operational Enhancements Derived Requirements (Ctd.)

- Enhanced Operations for En-Route and Oceanic Air-to-Air: ADS-B MASPS: First Four Columns, First 5 Rows.
- Improved Surface/Approach Operations: ADS-B MASPS, Table 3-4: First and Sixth Column, First 5 Rows.

FF Operational Enhancements Derived Requirements (Ctd.)

- Surface and Airport Vicinity Display for the Controller: ADS-B MASPS, Table 3-4, First and Sixth Columns, First 5 Rows. (Note Also Table 2-4, 2nd and 3rd columns)
- Use ADS-B in Non-Radar Airspace: ADS-B MASPS, Table 3-4, First Four Columns, First 5 Rows

FF Operational Enhancements Derived Requirements (Ctd.)

- ADS-B to Enhance Radar and Automation Performance: ADS-B MASPS: Table 3-4, First 4 columns, First 5 Rows
- For All Operational Enhancements: Integrity, Continuity, and Availability Requirements of ADS-B MASPS, Section 3.3.6

“MASPS-Derived” Criteria

- Simultaneous Approach Scenario of RTCA ADS-B MASPS (10 nmi)

“Implied” Evaluation Criteria

- Time to Implementation
  - Time to Availability of International Standards
  - Time to RF Spectrum Availability
  - Status of reduction to practice
- Ability to integrate and interoperate with legacy systems

Attachment G2

Summary of Identified MASPS Requirements

(MASPS Tables 2-4, 3-4, and Excerpts from MASPS Section 3.3.6)

Table 2-4a: Summary of ATS Provider Surveillance and Conflict Management Current Capabilities for Sample Scenarios[a]

	Operational Capability			
Information	En Route	Terminal	Airport Surface	Parallel Runway Conform Mon.
Initial Acquisition of A/V Call Sign and A/V Category	Within 24 sec.	within 10 sec.	within 10 sec.	n/a
Altitude Resolution (ft)	25	25	25	25
Horizontal Position Error	388 m @ 200 nmi 116 m @ 60 nmi 35 m @ 18 nmi	116 m @ 60 nmi 35 m @ 18 nmi	3 m. rms, 9 m. bias [15],[6], [11]	9 m.
Received Update Period[b]	12 sec. [10]	5 sec. [6]	1 sec.	1 sec.
Update Success Rate	98%	98%	98% [6]	98%
Operational Domain Radius (nmi)	200	60	5	10
Operational Traffic Densities[c] (# A/V)	1250 [6]	750 [6]	100 in motion; 150 fixed	50 dual; 75 triple; w/o filter: 150
Service Availability[d] (%)	99.999 [10] 99.9 (low alt)	99.999 [10] 99.9 (low alt)	99.999 [10]	99.9

Table 2-4b: Additional and Refined Capabilities Appropriate for ADS-B Supported Sample Scenarios[a]

	Operational Capability			
Information	En Route	Terminal	Airport Surface	Parallel Runway Conform Mon.
Altitude Rate Error[e] (1σ)	1 fps	1 fps	1 fps	1 fps
Horizontal Velocity Error (1σ)	5 m/s	0.6 m/s	0.3 m/s	0.3 m/s
Geometric Altitude	yes	yes	yes	yes
Turn Indication	yes	yes	TBD	yes

n/a (not applicable) = the requirement is not stressful and would not be higher than any other requirement, i.e., does not drive the design.

tbd = To be determined.

Notes (Table 2-4):

a) *References are provided where applicable. Else, best judgment was used to obtain performance data.*
b) *Received update period is the period between received state vector updates. A/V Call Sign and A/V Category can be received at a lower rate.*
c) *One or multiple ground receivers may be used in the operational domain to ensure acceptable performance for the intended traffic load. The numbers in the table indicate the number of aircraft expected to participate in or affect a given operation. (Refer to Table 3.3-1 for requirements which are based on operational traffic densities derived from the Los Angeles basin model)*
d) *Service availability includes any other systems providing additional sources of surveillance information.*
e) *Altitude accuracy: Some aircraft currently have only 100 ft resolution capability.*

Table 3.4: ADS-B Report Accuracy, Update Period, and Acquisition Range Requirements

	Aid to Visual Acquisition	Conflict Avoidance and Collision Avoidance	Separation Assurance and Sequencing	Flight Path Deconfliction Planning	Simul-taneous Approach	Airport Surface (note 5)
State Vector Acquisition Range	10 nmi	20 nmi	40 nmi	90 nmi (note 3); (120 nmi desired)	10 nmi	5 nmi
Mode-status Acquisition Range (note 8)	10 nmi	20 nmi	40 nmi	90 nmi (note 3) (120 nmi desired)	10 nmi	5 nmi
On Condition Acquisition Range (note 8)	n/a	n/a	n/a	90 nmi (note 3) (120 nmi desired)	10 nmi	TBD
Nominal Update Period (95th percentile) (note 6) (note 7)	<= 3 s (3 nmi) <= 5 s (10 nmi)	<= 3 s (3 nmi) (1 s desired, note 2) <= 7 s (20 nmi)	<= 7 s (20 nmi) <= 12 s (40 nmi)	<= 12 s	<= 1.5 s (1000 ft runway separation) <= 3 s (1 s desired) (2500 ft runway separation)	<= 1.5 s
99th Percentile State Vector Report Received Update Period (Coast Interval) (Note 7, 8)	<= 6s (3 nmi) <= 10 s (10 nmi)	<= 6 s (3 nmi) <= 14 s (20 nmi)	<= 14 s (20 nmi) <= 24 s (40 nmi)	<= 24 s	<= 3s (1000 ft runway separation) (1s desired, note 2) <= 7s (2500 ft runway separation)	<= 3 s
Permitted Total State Vector Errors Required To Support Application (1 sigma, 1D)	σ_{hp} = 200 m σ_{hv} = n/a σ_{vp} = 32 ft σ_{vv} = 1 fps	σ_{hp} = 20 / 50 m (note 1) σ_{hv} = 0.6/ 0.75 m/s (note 1) σ_{vp} = 32 ft σ_{vv} = 1 fps	σ_{hp} = = 20 / 50 m (note 1) σ_{hv} = 0.3/ 0.75 m/s (note 1) σ_{vp} = 32 ft σ_{vv} = 1 fps	σ_{hp} = 200 m σ_{hv} = 5 m/s σ_{vp} = 32 ft σ_{vv} = 1 fps	σ_{hp} = 20 m σ_{hv} = 0.3 m/s σ_{vp} = 32 ft σ_{vv} = 1 fps	σ_{hp} = 2.5 m (note 9) σ_{hv} = 0.3 m/s σ_{vp} = n/a σ_{vv} = n/a
State Vector Errors Budgeted for ADS-B (1 sigma, 1D) (Note 10)	σ_{hp} = 20 m σ_{hv} = 0.25 m/s σ_{vp} = 30 ft σ_{vv} = 1 fps (Note 11)					σ_{hp} = 2.5 m (note 9) σ_{hv} = 0.25 m/s σ_{vp} = n/a σ_{vv} = n/a

Definitions:
σ_{hp}: standard deviation of horizontal position error.
σ_{hv}: standard deviation of horizontal velocity error.
σ_{vp}: standard deviation of vertical position error.
σ_{vv}: standard deviation of vertical velocity error.

Notes:

1) The lower number represents the desired accuracy for best operational performance and maximum advantage of ADS-B. The higher number, representative of GPS standard positioning service, represents an acceptable level of ADS-B performance, when combined with barometric altimetery.

2) The analysis in Appendix J indicates that a 3-second report received update period for the full state vector will yield improvements in both safety and alert rate relative to TCAS II, which does not measure velocity. Further improvement in these measures can be achieved by providing a one-second report received update rate Further definition of ADS-B based separation and conflict avoidance system(s) may result in refinements to the values in the Table.

3) The 90 nmi range requirement applies in the forward direction. The required range aft is 30 nmi (40 nmi desired). The required range 90 degrees to port and starboard is 45 nmi (60 nmi desired) (see Appendix H).

4) n/a = not applicable; TBD = To be defined

5) Requirements apply to both aircraft and vehicles.

6) Supporting analyses for update period and update probability are provided in Appendices J and L.

7) Acceptable combinations of report update period (T) and update probability (P) are given by the formula $(1\text{-}P)^{TC/T} <= 0.01$ where TC is the 99th percentile report update period given in the table. For example, for conflict avoidance, TC = 6 sec.; a report update period of T=3 would require P=0.9 or greater. As a second example, for conflict avoidance, if P=0.5, then T must be 0.9 seconds or less.

8) The delay for MS or OC report updates after a MS or OC state change should be no more than the coast interval associated with the state vector report (with 95% confidence).

9) The position accuracy requirement for aircraft on the airport surface is stated with respect to the certified navigation center of the aircraft.

10) This row represents the allowable contribution to total state vector error from ADS-B.

11) The horizontal velocity error requirements to aircraft speeds of up to 600 knots. Accuracies required for velocities above 600 knots are TBD.

12) Specific system parameter requirements in Table 3.3-3 can be waived provided that the system designer shows that the application design goals stated in Appendix J or equivalent system level performance can be achieved.

13) Update periods for the SV have been emphasized in determining link related performance requirements in this table. Lower rates of MS and OC are under development. These reports should be made available to support the operational capabilities using considerations equivalent to the SV. The requirement should be optimized to ensure that the refresh/update of reports is appropriate for the equipment classes and the operations being supported. Refer to the analysis presented in Appendix L for further details.

3.3.6 ADS-B System Quality of Service

3.3.6.1 Required Monitoring Performance

A key concept in the definition of future ATS systems is that of Required Monitoring Performance (RMP). The term “Monitoring Performance” refers to capabilities of an airspace user to monitor other users and be monitored by other users and ATS at a level sufficient for participation of the user in both strategic and tactical operations. RMP is intended to characterize aircraft path prediction capability and received accuracy, integrity, continuity of service, and availability of a monitoring system for a given volume of airspace and/or phase of operation. Important monitoring system parameters such as state vector report received update rate can be derived from the primary RMP parameters.

Aircraft path prediction capability is defined by a 95 percent position uncertainty volume as a function of prediction time over a specified look ahead interval. Monitoring integrity (assurance of accurate, reliable information), where there is availability of service, must be defined consistent with the desired airspace application. Monitoring continuity of service and availability also must be defined consistent with the desired airspace application.

Development of the RMP concept is in progress by RTCA. Companion concepts of Required Navigation Performance (RNP) and Required Communications Performance (RCP) have also been developed in order to provide the necessary characterization of Required System Performance (RSP) of aviation Communications, Navigation, and Surveillance (CNS) systems. RMP, RNP, and RCP are central to the future FANS/ATM system and the realization of Free Flight. ADS-B delivery technologies, data definition, and applications must conform to appropriate RMP specifications on an end-to-end basis.

3.3.6.2 Failure Mode and Availability Considerations

Navigation and radar surveillance in the horizontal dimensions are independent; this independence is beneficial under certain failure modes. Today, an aircraft with failed navigation capability may get failure mode recovery vectors from ATS based on SSR/PSR tracks. Today, an aircraft with a failed transponder may still report navigation based position information to ATS for safe separation from other traffic even if no PSR is available. On the other hand, a navigation capability failure in an ADS-B only surveillance environment results in both the aircraft and ATS experiencing uncertainty about the aircraft’s location. The operational impact of such a failure depends upon the nature of the failure: i.e., a single unit failure, or an area wide outage. Additional factors include the duration of the failure, the traffic density at the time of the failure, and the overall navigation and surveillance architecture. Detailed treatment of these issues should consider the failure mode recovery process in the context of the service outage duration and the total CNS environment. Figure 3.3-2 suggests how such a failure mode recovery process depends upon the total ATS architecture. Different states may implement different ATS architectures.

It is anticipated that ADS-B will be used as a supplemental means of surveillance for some ATS-based airspace operations during a transition period leading to full ADS-B equipage. When used as a supplemental means of surveillance, ADS-B adds availability within a larger surveillance system. Primary means of surveillance is defined as a preferred means (when other means are available) of obtaining surveillance data for aircraft separation and avoidance of obstacles. Use of ADS-B as a sole means of surveillance presumes that aircraft can engage in operations with no other means of surveillance. If ADS-B were to be used as a sole means of surveillance, availability would be calculated using only ADS-B, aircraft sources, and applications. ADS-B is not expected to be used as a sole means of ATS surveillance for the near future in US domestic airspace.

Where the ADS-B System is used as a supplemental means of surveillance, the ADS-B system is expected to be available with a probability of at least 0.95 for all operations, independent of the availability of appropriate inputs to the ADS-B system. Where the ADS-B System is used as a primary means of surveillance, the system is expected to be available with a probability of at least 0.999 for all air-air operations.

If an ADS-B system is used as a primary means of surveillance, then a supplemental surveillance system, independent of the navigation system, is expected to be available. The overall surveillance system will need to satisfy fail-safe operation of navigation and surveillance, i.e., a failure of the navigation system will not result in a failure of the surveillance function. This will enable ATS to provide an independent means of guidance to aircraft losing all navigation capability. The overall requirement for the surveillance system is adequate availability of the surveillance function, independent of navigation system availability. Where this requirement cannot be satisfied in a system intended for primary means of surveillance, the avionics and support infrastructure should be designed such that the simultaneous loss of both navigation and surveillance is extremely improbable. The expected availability of the total surveillance system is at least 0.99999, independent of navigation system availability.

ADS-B Availability Requirements

Availability is calculated as the ADS-B System Mean-Time-Between-Failures (MTBF) divided by the sum of the MTBF and Mean-Time-To-Restore (MTTR). ADS-B equipage is defined to be available for an operation if the following conditions are met: (1) ADS-B equipage outputs are provided at the rates defined in Table 3.3-3 and (2) the ADS-B reports have the integrity required by Section 3.3.6.5, For the purposes of calculating availability, an ADS-B transmission subsystem is considered to be one participant's message generation function and message exchange (transmission) function. An ADS-B receiver subsystem is considered to be one participant's message exchange (receiver) and one report generation function.

ADS-B availability shall (R3.24) be 0.9995 for class A0 through class A3 and class B0 through class B3 transmission subsystems. ADS-B availability shall (R3.25) be 0.95 for class A0 receiver subsystems. Class A1, A2, and A3 receiver subsystems shall (R3.26) have an availability of 0.9995. Specification of Class C receiver subsystem availability requirements are beyond the scope of this MASPS.

High transmission availability (0.9995) is required of all classes in order to support the use of ADS-B as a primary means of surveillance for ATS. The combination of 0.9995 availability of transmission and 0.9995 availability of receive for classes A1 through A3 results in availability of 0.999, allowing the use of ADS-B as a primary means of surveillance for some air-to-air operations. A lower availability is permissible for Class A0 receiver subsystems as ADS-B is expected to be used as a supplemental, rather than as a primary tool of separation, for this class.

3.3.6.4 ADS-B Continuity of Service

The probability that the ADS-B System, for a given ADS-B Message Generation Function and in-range ADS-B Report Generation Processing Function, is unavailable during an operation, presuming that the System was available at the start of that operation, shall (R3.27) be no more than 2×10^{-4} per hour of flight. The allocation of this requirement to ADS-B System Functions should take into account the use of redundant/diverse implementations and known or potential failure conditions such as equipment outages and prolonged interference in the ADS-B broadcast channel.

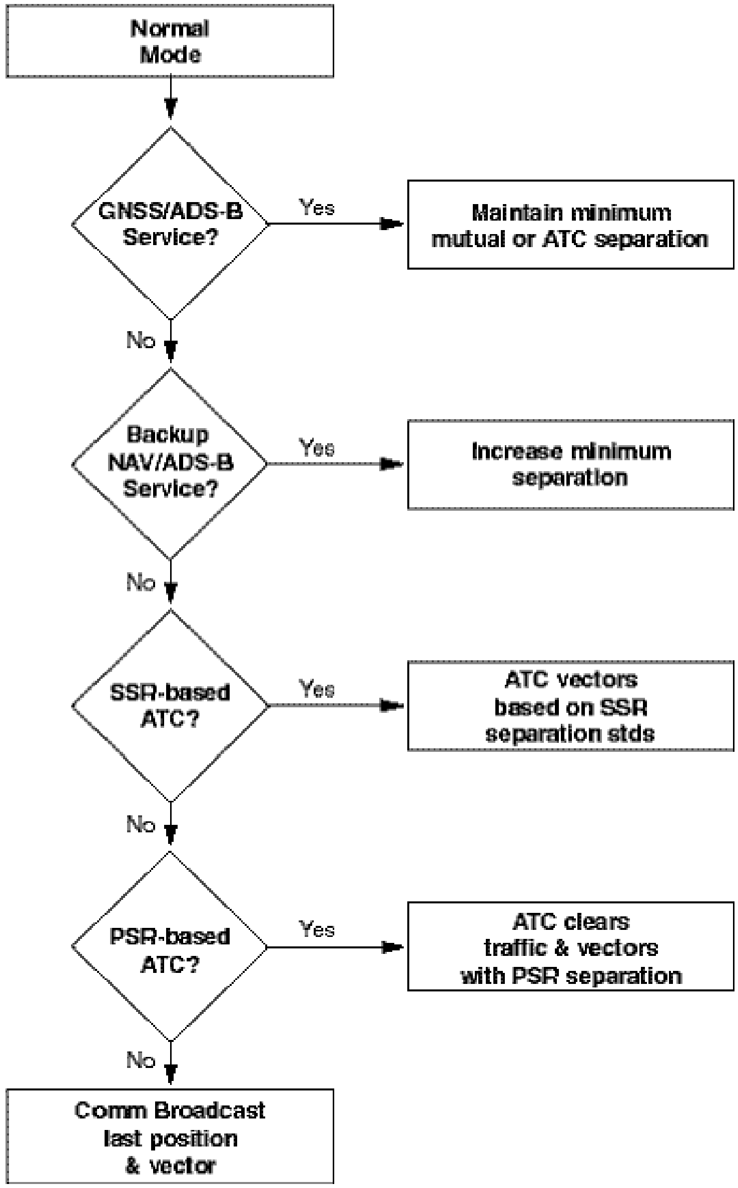


Figure 3.3-2. GNSS/ADS-B Surveillance/Navigation Failure Recovery Modes

3.3.6.5 ADS-B Integrity

ADS-B integrity is defined in terms of the probability of an undetected error in a report received by an application, given that the ADS-B system is supplied with correct source data. The integrity of the ADS-B System shall (R3.28) be 10^{-6} or better on a per report basis. Appendix I contains information relevant to the development of high integrity end-to-end surveillance, conflict detection and management, and separation assurance applications using ADS-B.

Demonstration of compliance with ADS-B System integrity requirements will require a safety assessment to evaluate the System's implementation against known or potential failure conditions such as encoding, decoding and processing errors and interference in the ADS-B channel.

Attachment G3

Excerpt from LET Presentation to the Safe Flight 21 Steering Committee

Approval of TIS-B Link Evaluation Criteria

Link Evaluation Criteria for TIS-B

- Assumptions:
  - If the TIS-B ground infrastructure for a given link "hears" an ADS-B participant on that link, no TIS-B information on that participant will be broadcast on that link
  - TIS-B performance is driven by existing radars (data collectors). [Note: implications of this are different for TIS vs. TIS-B] and is Inherently Different than that of ADS-B

Link Evaluation Criteria for TIS-B

- Proposed TIS-B Link Evaluation Requirements
  - 80 bits per target (24 of which is a/c identifier)
  - Each target must be received once per 5 seconds with 90 percent probability
  - 120 meter LSB on latitude and longitude
  - 100 feet LSB on altitude
  - Velocity Is Required

Traffic Scenarios

This appendix addresses assumptions used in the link characterization regarding the traffic scenarios and the operational environment.

Traffic Scenario Assumptions

For the ADS-B data link evaluation, there are a total of five air traffic scenarios which will be used to evaluate data link performance. Four of these scenarios involve two geographic areas (Core Europe and LA Basin), each assessed for each of two time periods (1999 and 2020 for the LA Basin and 2005 and 2015 for Core Europe). The two airspace regions are quite different in character, which will provide two diverse views of the data link performance. The fifth scenario is intended to model lower density airspace (which is representative of the majority of the world's airspace). The LET has generated five sets of aircraft, one for each of the data link scenarios, for common use in the evaluation of the three system candidates. Figure H-1 depicts the total traffic for each scenario as a function of range.

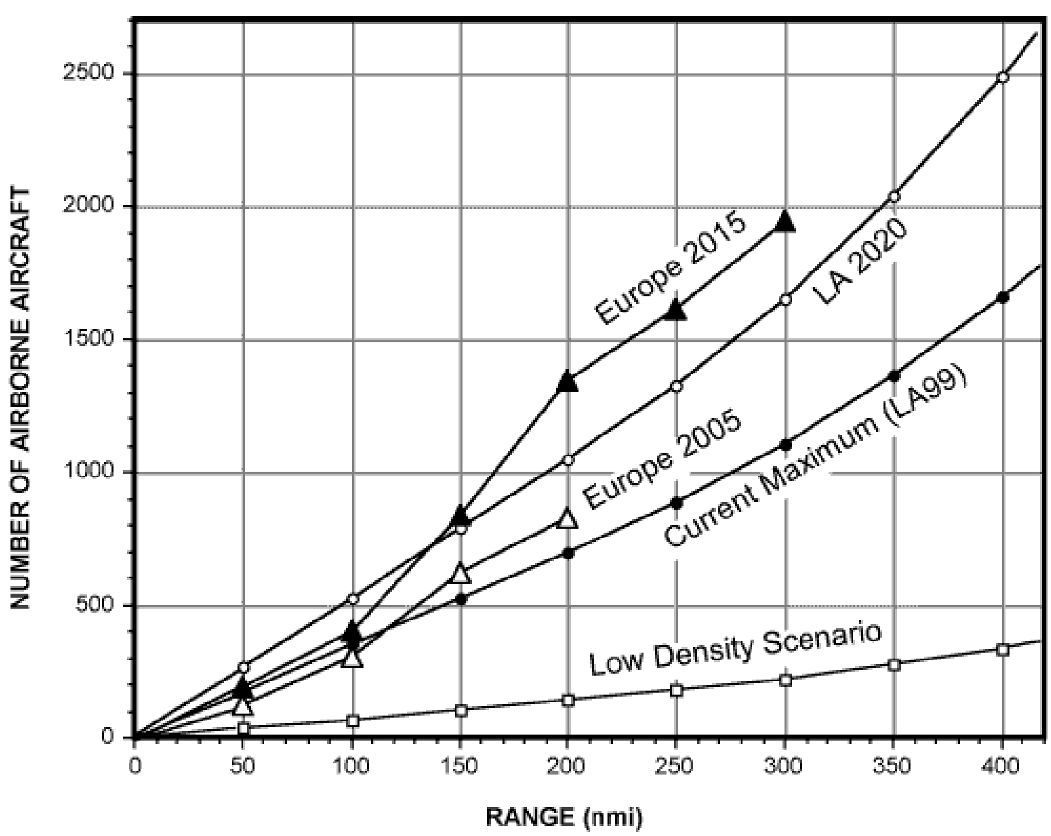


Figure H-1: Cumulative range distributions for the five aircraft traffic scenarios

The following assumptions went into generating the airborne and ground aircraft for the LA Basin 1999 scenario:

- The density of airborne aircraft was taken to be:
  - Constant in range from the center of the area out to 225 nautical miles (3.5 aircraft/nm), (i.e., the inner circle of radius one nm would contain approximately 3.5 aircraft, as would the ring from 224 to 225 nm) and
  - Constant in area from 225 nm to 400 nm (.0025 aircraft/nm^2).
- There were assumed to be a fixed number of aircraft on the ground (within a circle of radius 5 nm at each airport), divided among LAX, San Diego, Long Beach, and five other small airports. Half of the aircraft at each airport were assumed to be moving at 15 knots, while the other half were stationary.
- The altitude distribution of the airborne aircraft was assumed to be exponential, with a mean altitude of 4500 feet. This distribution was assumed to apply over the entire area.
- The airborne aircraft were assumed to have the following average velocities, determined by their altitude. The aircraft velocities for aircraft below 25000 feet will be uniformly distributed over a band of average velocity +/- 30 percent.
  - 0-3000 feet altitude 130 knots
  - 3000-10000 ft 200 knots
  - 10000-25000 ft 300 knots
  - 25000-up 450 knots
- The aircraft are all assumed to be moving in random directions.
- All aircraft above 10000 feet are assumed to be either ADS-B MASPS equipage class A3 (75%) or A2 (25%) (for further definition of the equipage classes, see RTCA DO-242, Table 3-3a), while below 10000 feet, the ratios are adjusted to give the entire ensemble of aircraft the following proportions of equipage:
  - A3 30%
  - A2 10%
  - A1 40%
  - A0 20%

The scenario for the current high density LA Basin case contained a total of 1796 aircraft: 787 within the core area of 225 nm, 859 between 225-400 nm, and 150 on the ground. Of these aircraft, 314 lie within 60 nm of the center. (This includes aircraft on the ground.) Around ten percent of the total number of aircraft are above 10000 ft in altitude, and more than half of the aircraft are located in the outer (non-core) area of the scenario. The future (year 2020) high density LA Basin scenario was generated using exactly the same assumptions, with the aircraft densities increased by 50 percent, resulting in a total of 2694 aircraft, proportionately distributed the same way as the current scenario.

An attempt was made to at least partially account for the expected lower aircraft density over the ocean. In the third quadrant (between 180 degrees and 270 degrees), for distances greater than 100 nm from the center of the scenario, the density of aircraft was reduced to 25 % of the nominal value used. The other 75 % of aircraft which would have been placed in this area were distributed uniformly among the other three quadrants at the same range from the center. This results in relative densities of 1:5 between the third quadrant and the others.

For the Core Europe 2005 scenario, an aircraft distribution has been provided by Eurocontrol, which will be used in the evaluation. This distribution includes airborne aircraft only. The basic assumptions used for the Core Europe 2005 scenario are as follows:

- There are five major TMAs (Brussels, Amsterdam, London, Paris, and Frankfurt), each of which is characterized by:
  - an inner region (12 nm radius), which contains 19 aircraft at lower altitudes,
  - an outer region (50 nm radius), which contains 69 aircraft at mid to higher altitudes.
- These aircraft are assumed to be symmetrically distributed rotationally, and all of the aircraft in an altitude band are assumed to be at the same altitude and to be travelling at the same altitude-dependent velocity (see LA Basin above for average velocity values by altitude band).
- Superimposed over these aircraft is a set of airborne en route aircraft, which are distributed uniformly over a square of side 300 nm. These aircraft are distributed over four altitude bands, ranging from low to upper altitudes. They also travel at velocities which are altitude dependent.

This scenario includes a total of 838 aircraft. The Core Europe 2005 scenario is not consistent with the LA Basin and Core Europe 2015 scenarios, in that the area defined by the scenario is square rather than circular, and is smaller in total area as well.

For the Core Europe 2015 scenario, the distributions and assumptions made were taken directly from the Eurocontrol document entitled “High-Density 2015 European Traffic Distributions for Simulation,” dated August 17, 1999. This scenario is fairly well-defined and straightforward to apply.

This scenario includes a total of 2091 aircraft (both airborne and ground) is described in greater detail, and is based on the following assumptions:

- The five major TMAs remain the same, with some modifications to their characterizations:
  - The inner region (12 nm radius) contains 29 aircraft at lower altitudes.
  - The outer region (50 nm radius) contains 103 aircraft at mid to higher altitudes,
  - There are assumed to be 25 aircraft on the ground, within a 5 nm radius, plus another 25 aircraft randomly distributed throughout the entire scenario area.
- These aircraft are still assumed to be symmetrically distributed rotationally, but, unlike the 2005 scenario, the aircraft in an altitude band are assumed to be uniformly distributed throughout the band. However, all aircraft in the same band are still assumed to be travelling at the same band-dependent velocity.
- Superimposed over these aircraft is a set of airborne en route aircraft, which are distributed over a circle of radius 300 nm. These aircraft are distributed over four altitude bands, ranging from low to upper altitudes. They also travel at velocities which are altitude band dependent.

For both the Core Europe 2005 and 2015 scenarios, all aircraft are assumed to be ADS-B equipped. The equipage levels have been adjusted to be around 40% A3, 40% A2, and 20% A1, according to altitude. The lower percentages of A0 and A1 aircraft than those found in the LA Basin scenarios reflect differences in operating conditions and rules in European airspace.

The two geographical areas which underlie the four scenarios discussed above (LA Basin and Core Europe) correspond to very different types of situations for an aircraft to operate in, and thus should provide two diverse environments for evaluation. The LA Basin scenario contains only about 11% of all airborne aircraft, which are above 10000 ft in altitude, while the Core Europe scenario has around 60% above 10000 ft. Thus, there will be vastly different numbers of aircraft in view for the two scenarios. Additionally, the aircraft density distributions are also quite different, which will also place different stresses on the data link systems.

The fifth scenario, for simplicity, has been developed by scaling the current LA Basin distributions downward by a factor of five.

The LET is of the view, using engineering judgement, that adding additional aircraft density to the future LA Basin or Core Europe 2015 scenarios is not likely to provide further discrimination between the ADS-B link candidates. Should this prove not to be the case, one or more scenarios with greater density will be evaluated.

Channel Interference Environment

UAT and VDL4 are expected to be implemented as dedicated channel systems. As such, interference to these systems is likely to be dominated by self-interference. On the other hand, the Extended Squitter system for ADS-B shares the 1090 MHz frequency channel with existing users (for instance, both SSR and TCAS). Thus, both self-interference and co-channel interference effects on performance must be examined. Identification and characterization of the mechanisms necessary to assess Extended Squitter performance in the operational scenarios selected for LET evaluation follow. The LET notes that adjacent channel interference effects will be thoroughly evaluated, as part of the spectrum allocation process, for UAT and VDL Mode 4.

Existing SSR and TCAS systems cause aircraft transponders to transmit ATCRBS replies, short (64 microseconds) Mode S signals, and/or long (120 microseconds) Mode S signals, any of which may interfere with reception of Extended Squitter messages. The net effect of the usage of 1090 MHz by SSR and TCAS systems may be fully accounted for by describing the 1090 MHz reply distribution (the number and amplitude of the replies seen by a victim receiver where reception of Extended Squitters is taking place). The 1090 MHz reply distribution may be modeled through examination of aircraft distributions and interrogators (both TCAS and SSR), and validated through direct measurement of the 1090 MHz reply distribution in existing environments.

The evolution of ground secondary radar systems utilized by the FAA should reduce the ATCRBS reply rates per aircraft. Increased utilization of monopulse azimuth processing in SSR interrogators (including any upgrade of SSR interrogators operated by the military) and improvements in TCAS should contribute to this reduction. A reduction in ATCRBS reply rates associated with FAA-operated Mode S sensors will also accompany the removal of a non-standard configuration in place today that was implemented to maintain ground surveillance on certain SSR transponders that do not reply to an ATCRBS-only interrogation from a Mode-S-capable interrogator. Efforts are currently underway to justify the removal of this workaround. The timing for removal of the workaround is unknown. The assumption made for scenario purposes is that Mode S sensors will have the workaround removed before 2020.

The ground and airborne elements which influence interference rates anticipated for Extended Squitter are being identified and quantified for use in future evaluations by the LET and Eurocontrol.

Summary of ADS-B/Situational Awareness Link Modeling and Simulation

ADS-B information exchange capabilities in various operational environments are determined by a number of factors: pair-wise radio link signal level limitations, ADS-B message format features, receiver and message decoder characteristics, the radio net access protocol employed, the number and distribution of users within detection range sharing this net, and message broadcast rates for each of these units. The high traffic densities forecast for future scenarios preclude operational evaluation of any proposed system design in these future environments. A shared channel concept faces the additional requirement of representing the future co-channel interference levels associated with multiple use of the channel. For example, the need to emulate future SSR and TCAS associated interference levels on the shared use 1090 Mhz channel restricts flight tests of this alternative in any environment other than those existing today.

Analytical models and detailed simulations of proposed designs operating in future scenarios are therefore required to assess expected capabilities in stressed circumstances. Accurately modeling future capabilities for different designs in a fair way, however, is challenging. Since validation of simulation results in future environments is unrealistic, other means of verification such as those discussed in the following are required. System characteristics represented in these simulations should agree with actual measurements on components of the proposed design, e.g., bench measurements on prototype equipment and calibrated flight test data should be used for the modeled link budget and receiver/decoder capabilities. Similarly, flights monitoring interference levels associated with current SSR and TCAS, coupled with a suitable interference model, support estimates of how these conditions may change in future scenarios. Credibility of any simulation results for future scenarios also requires that they be able to model current conditions and provide results that appropriately agree with measurements made under these conditions.

Many of the preferred tools require further development. Interim results will be developed from existing tools available to the LET. These existing tools will also be used as cross-checks for the final detailed simulations and models.

The following table summarizes the modeling and simulation activities associated with evaluating the three ADS-B candidates. These efforts are discussed in terms of their utility in four key areas: representing RF link characteristics, describing scenario traffic and other sources of co-channel interference, examining channel access and net protocol behavior, and support of spectrum management issues resolution.

Table J-1: Summary of ADS-B/Situational Awareness Link Modeling and Simulation Activities

Evaluation Topic	1090 MHz Squitter	UAT	VDL Mode 4
ADS-B RF Link Models including effects of: -antenna patterns -transmit power -probability of decode versus signal/noise ratio and versus signal/interference -own aircraft receive suppression -single versus diversity antenna	**Lincoln Laboratory:** pulse-level simulation uses sampled RF video as input to software implementation of reception processing (including decoder processing). Output is probability of correct reception as a function of range. Can also be used to process airborne recordings. Also, a track-level simulation which includes even-odd position messages, top-bottom antenna switching, etc. Output is probability of establishing a track including all needed information (cross check and validation of waveform model and detailed model, assist APL in generation of interim results). **Ohio State University:** L-band antenna pattern modeling to predict antenna patterns based on GA aircraft configuration and antenna placement (use by LET will depend upon further evaluation). **Volpe:** Model of interrogator/surface targets in preparation, expected completion in November 99. APL will work with Volpe to ensure that further development of their detailed model will meet LET requirements (to be used as primary detailed model). Expected completion April 00. **Mitre:** as in UAT column, used same way. **DERA:** detailed model of transponder and interrogator performance exists, will provide results and documentation to LET (cross check results of modeling activities). **APL:** will perform bench testing of several 1090 MHz receivers (TBD) at the WJHTC in collaboration with FAA/Lincoln personnel and develop waveform models from the results.	**Mitre:** set of individual modeling tools for link, top/bottom antenna, multipath, receiver/decoder, and signal variations (validate quick look flight test data, flight test planning, provide spot cross check on detailed models, no further development planned). **Ohio State University:** L-band antenna pattern modeling to predict antenna patterns based on GA aircraft configuration and antenna placement (use by LET will depend upon further evaluation). **APL:** developing detailed model, projected completion January 00. **APL:** waveform model is based on bench tests, completed.	**Swedish CAA:** SPS simulation generally accepts external definition of aircraft distribution and movements (straight line, simple velocity) and allocates slots according to pre-defined algorithm. (Development needed, to add, in priority, waveform model, RF amplitude (variations in transmit power and receiver sensitivity), antenna gain variation, transient effects with channel management, TIS-B, FIS-B, hidden terminal effect). **APL/Eurocontrol** will either implement necessary modifications to SPS or develop alternatives. Expected completion date: April 00. **Mitre:** augmentation to SPS (formula-based) to simulate Gaussian antenna gain variation; analysis to provide quick-look cross check on antenna gain variation effects on "Robin Hood" (used as cross check on detailed (SPS-based) model. **APL:** VDL Mode 4 waveform model is based on bench tests, completed.
Traffic distribution and dynamics for scenario operational domains (surface, terminal, en route and over-flights) -Range -Altitude -Traffic mix -Shared channel interference sources for 1090 MHz	**LET:** defined traffic scenarios common to all links (no further development planned for 1090-specific questions)	**LET:** defined traffic scenarios common to all links (no further development planned for UAT-specific questions)	**LET:** defined traffic scenarios common to all links (include, for use on all systems, 3D dynamic aircraft distribution and movements to exercise Rapid Net Entry in VDL Mode 4)

Evaluation Topic	1090 MHz Squitter	UAT	VDL Mode 4
Channel Access and Network Protocol including consideration of: -net management concept -channel access scheme -hand-off between different channels and/or channel access modes -number of channels aircraft monitors -required coordination between ground stations -decision tree for slot assignment in VDL Mode 4 -recovery mechanisms/modes for GPS outage or equipment test	**Mitre:** same as in UAT column, except use capability to model interrogators (use as cross check to validate detailed models).	**Mitre:** analysis tool draws upon external traffic distribution definition and receiver model developed from Mitre RF model above to estimate probability of reception in face of co-channel interference (cross check) **APL:** currently developing detailed model, expected completion January 00.	**Eurocontrol/APL:** exercise models defined above.
Frequency Planning Support -Compatibility with existing users (and adjacent users) of spectrum band	**Joint Spectrum Center:** models ground interrogators/airborne TCAS/ airborne transponder/surface users, outputs fruit rates, documents effects of squitter on existing users (documented results to be used as cross check against LET models, performance estimates). **Volpe:** detailed model of interrogators/surface targets under development (model schedules for completion in November 99). **Volpe/APL:** addition of TIS-B, FIS-B effects into detailed model necessary to assess impact of TIS-B, FIS-B on existing users. Expected completion April 00.	**APL:** waveform model used to estimate required frequency spectrum (need to define which legacy systems are candidates for compatibility analysis and develop appropriate models to confirm)	**Ohio University:** measured compatibility of VDL Mode 4 with VOR (LET to review report). **APL:** bench testing completed, can be an input to defining a spectrum plan. **DFS (German CAA):** completed DSB-AM voice compatibility testing and initial data analysis for VDL Mode 4. **APL/Eurocontrol:** to assess necessity/scope of further modeling/simulation activities to support frequency planning.